

**NASA Technical Memorandum 100614**

**ON-ORBIT TECHNOLOGY EXPERIMENT  
FACILITY DEFINITION**

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# ON-ORBIT TECHNOLOGY EXPERIMENT FACILITY DEFINITION

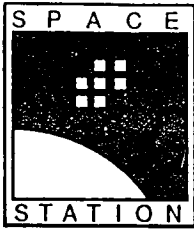
## INTRODUCTION

Future spacecraft will be larger and more complex, and their performance requirements will be more demanding. Advancements in many technology areas are needed if the increased performance requirements are to be met. Long range technology goals need to be identified and a logical progression of experiments and demonstrations must be established so that these goals will be reached.

Many technology development experiments have been proposed that will be conducted from the Orbiter or while attached to the Space Station. The Space Station experiments are described in the NASA Mission Requirements Data Base (MRDB). Others were proposed at the In-Space Research, Technology and Engineering (RT&E) Workshop held in October of 1985. Experiments in seven technology "theme areas" were described at the workshop.

A study to assess and evaluate these proposed experiments was conducted to identify on-orbit integrated facility needs to support in-space technology experiments on the Space Station. The first task was to examine the proposed technology development missions (TDMX's) from the model mission set and other proposed experimental facilities, both individually and by theme, to determine how and if the experiments might be combined, what equipment might be shared, what equipment might be used as generic equipment for continued experimentation, and what experiments will conflict with the conduct of other experiments or Space Station operations. Then, using these results, determine specific on-orbit facility needs to optimize the implementation of technology payloads. Finally, develop one or more scenarios, design concepts, and outfitting requirements for implementation of onboard technology experiments.





# **On-Orbit Technology Experiment Accommodation**

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## **OBJECTIVES**

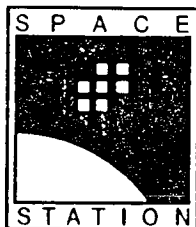
- **Examine interaction of proposed TDMX's and experimental facilities**
- **Determine specific on-orbit facility needs to optimize the implementation of technology payloads**
- **Develop one or more scenarios, design concepts, and outfitting requirements for implementation of onboard technology experiments**

## RT&E Workshop Theme Areas

The NASA In-Space Research, Technology and Engineering (RT&E) Workshop was held in Williamsburg, Va in October of 1985. Its purpose was to bring together representatives from the government, industry and universities to present candidate in-space experiments in support of space technology development and to derive requirements for space station facilities to support them. It initiated an interactive process for building a national in-space experiments program.

The pertinent technology topics were divided into the seven theme areas and subcategories shown in this figure. To support the development of a long range technology program, the following recommendations were made:

1. Develop an on-going RT&E university and industry advisory group;
2. Continue in-space RT&E symposia to act both as outreach mechanisms and as working sessions to refine the TDM data base;
3. Develop an RT&E information clearinghouse;
4. Develop and continue the new experiments outreach activity announced at the RT&E workshop;
5. Develop an "impacts assessment group" which will focus its energy on identifying experiment accommodation requirements to impact the design of in-space facilities, i.e., space station and others.



# RT&E Workshop Theme Areas

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## Space Structure (Dynamics & Control)

- Advanced Structural Concepts
- Structural Dynamics
- Advanced Control Concepts
- Structure/Control Interaction
- Structure/Control Sensors

## Fluid Management

- Fuel Storage & Transfer
- Fluid Behavior
- Sensor Concepts

## Space Environmental Effects

- Material Durability
- Atomic Oxygen
- Ultraviolet/Vacuum
- Electron/Proton
- Plasma
- Contamination

## Energy Systems & Thermal Management

- Advanced Photovoltaics
- Solar Dynamics
- Nuclear
- Advanced Thermal Concepts
- Laser Power

## Information Systems

- Sensor Systems
- Computer/Data Systems
- Communications Systems

## Automation & Robotics

- Mobility
- Dextrous Manipulation
- Supervise/Autonomous Robotics
- Advanced Concepts

## In-Space Operations

- Advanced Life Support Systems
- Biomedical Research
- Tethers
- Maintenance and Repair
- Orbital Transfer Vehicles
- System Testing
- Propulsion
- Material Processing

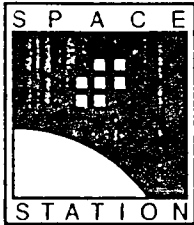


## In-Space RT&E Facilities Wish List

A review of the conclusions and recommendations presented by the panels of the seven theme areas revealed the list of desired facilities shown in this figure. The size and complexity of the desired facilities range from simple pallets that support specimens while being exposed to the space environment to complete laboratory modules. Clearly, if all wishes were granted, the size of the space station would increase by a factor of two or three. Therefore, a compromise must be reached in terms of the facilities to provide an adequate opportunity for all technology areas. This may be accomplished by consolidating experimental facilities or by time-phasing the requirements.

Each of the seven technology theme areas are reviewed separately in this report. For each theme area, applicable experiments are reviewed to determine their facility requirements and the potential for consolidation. This study deals only with the requirements of externally attached facilities, so the first task is to determine the desired location for each type of experiment within the theme area. Then a list of candidate experiments is presented. Next, a review of these experiments results in lists of experiments that can be consolidated because of common hardware or related goals. An assessment of these groupings leads to the description of recommended testbeds that support technology development experiments.

The report concludes with an overall summary of the recommended testbeds.



# In-Space RT&E Facilities Wish List

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## Space Structure (Dynamics & Control)

Structural Concepts Research Facility

- Materials research
  - Advanced structural concepts
  - Fabrication technology
  - On-orbit structural repairs
- External Testbeds
- Antennas
  - Segmented structures
  - Inflatables
  - Actively controlled structure

## Fluid Management

Fluid Management Facility

- Fluid storage, measurement and transfer
- Long term cryogenic storage
- Two phase fluid management
- Reliquefaction

## Space Environmental Effects

Materials Exposure Facility

- External
- Laboratory

Electronics Test Facility

Materials Production Laboratory

Environmental Research Facility

- Natural environment
- Imposed environment

## Energy Systems & Thermal Management

Power Systems Facility

- Solar (photovoltaic, solar dynamic, laser)
- Nuclear

Thermal Management Facility

- Radiators
- Thermal energy storage

## Information Systems

Sensor Systems Technology Laboratory

- Sensor development, verification & maint.
- Algorithm development & confirmation

Computer/Data Systems Laboratory

Communication Systems Facility

- Antenna range
- Acoustic measurements

## Automation & Robotics

Automation & Robotics Facility

- External & internal robots
- Maintenance & research laboratory

## In-Space Operations

Advanced Life Support System Lab (CELSS)

Life Science Research Facility (LSRF)

Tether Systems Facility

Satellite Maintenance & Repair Facility

Orbital Transfer Vehicle Servicing Facility

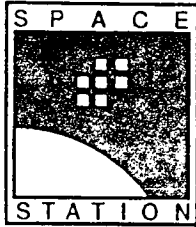
System Test Facility

Propulsion Research Facility

Material Processing Laboratory

General On-Orbit Facilities Requirements,  
Space Structure (Dynamics and Control)

This chart shows the required locations for experiments within the Space Structures (Dynamics & Control) theme area. In general, the primary location (indicated by the bold check marks) for all the experiments is external to the space station. With one exception, all are attached to the space station: advanced control concepts apply to both attached experiments and free flying spacecraft. Secondary locations (indicated by the light weight check marks) for some experiments are internal to space station modules. These experiments would include sensors and small size structural experiments.



# General On-Orbit Facilities Requirements, Space Structure (Dynamics & Control)

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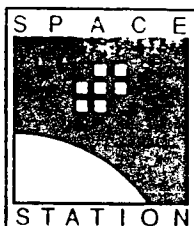
Experiment Category	Location				Comments
	Internal Press.	External Press.	Attached Unpress.	Remote	
Advanced Structural Concepts	✓		✓		Primary location is external. Some small structural experiments can be conducted in a pressurized module (small deployable structures, joints, latches, etc.)
Structural Dynamics	✓		✓		Primary location is external. Tests of small components or small scale structures can be done in a pressurized module.
Advanced Control Concepts			✓	✓	Needs large externally attached structures and/or free-flyers.
Structure/Control Interaction			✓		Needs large externally attached structures.
Structure/Control Sensors	✓		✓		Sensor & actuator experiments can be done to a limited degree in a pressurized module, but primary experiments are conducted on external/attached structure.



Area of interest

Space Structure (Dynamics & Control)  
Experiments Considered

This is a composite list of space structures experiments contained in the NASA Mission Requirements Data Base (MRDB) and those that were presented at the RT&E workshop. The experiments accompanied by an asterisk (\*) are representative of experiments that will occur within the first three years after space station initial operating capability (IOC).



# Space Structure (Dynamics & Control)

## - Experiments Considered -

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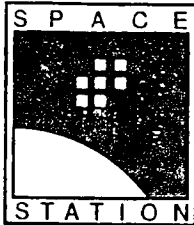
<u>TDMX</u>	<u>TITLE</u>
2061	Large Space Structures
2062	Space Station Modifications
2063	On Orbit Spacecraft Assembly and Test
2064	Advanced Antenna Assembly/Performance
2065	Ion Beam Cold Welding
2066	Inflatable/Rigidizable Structural Element
2071*	Flight Dynamics Identification
2072*	Spacecraft Strain & Acoustic Sensors
2073	Advanced Structural Dynamics/Controls
2411*	Advanced Adaptive Control
2412*	Distributed Control Experiment
2413*	Dynamic Disturbance Experiment
2414	Advanced Controls
2421	Active Optic Technology
2422	Thermal Shape Control
2431	Advanced Control Device Technology
2432	Pointing and Isolation Devices
----	Fiber Optic Sensors in Space Applications
----	Berthing & Docking Sensor
----	In-Space Actively Controlled Structure
----*	Space Station System Performance Technology
----	Precision Optical System Assembly
----*	Large Space Antenna (Reflectors)
----*	TDM for LDR
----	Polymeric Materials for Space Mechanisms
----	Environmental Influence on Structural Dynamics
----	Attitude Control & Energy Experiment

\* IOC Timeframe

## Space Structure (Dynamics & Control) Consolidation Within Theme

The Space Structures experiments are grouped into six categories, as shown in the next two figures:

1. Space Station Dynamics and Controls - These experiments are designed to determine the dynamic characteristics of the space station structure and to develop methods for its control.
2. Antenna Experiments - Five experiments have been identified that demonstrate the construction of a large antenna system, the determination of its structural dynamic characteristics, the adjustment and control of its surface figure, and the control of dynamic disturbances.
3. Large Precision Segmented Structures - The goal of these experiments is to construct a large segmented optical system and to control the segments to maintain a high precision reflector surface.
4. Satellite Servicing - This experiment demonstrates the assembly and checkout of a spacecraft at the space station.



# **Space Structure (Dynamics & Control)**

## **- Consolidation Within Theme -**

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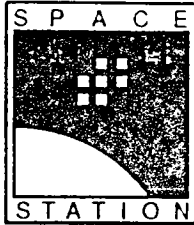
### **Experiment Groupings:**

- **Space Station Dynamics & Control**
  - 2073 Advanced Structural Dynamics/Controls**
  - 2414 Advanced Controls**
  - - - - Space Station System Performance Technology**
- **Antenna Experiments**
  - - - - Large Space Antenna (Reflectors)**
  - 2071 Flight Dynamics Identification**
  - 2411 Advanced Adaptive Control**
  - 2412 Distributed Control Experiment**
  - 2413 Dynamic Disturbance Experiment**
- **Large Precision Segmented Structures**
  - 2421 Active Optic Technology**
  - - - - TDM for LDR**
  - - - - Precision Optical System Assembly**
- **Satellite Servicing**
  - 2063 On-orbit Spacecraft Assembly and Test**



Space Structure (Dynamics & Control)  
Consolidation Within Theme (Continued)

5. Space Structures Construction and Control - The ability to construct and modify large space structures in space is demonstrated by some of these experiments. Others demonstrate the technologies necessary to establish and maintain accurate structural shapes.
6. Sensors, Actuators & Components - The goal of these experiments is to demonstrate advanced concepts for sensors required for docking, for the determination of structural integrity and dynamic characteristics, for attitude control, and for pointing and isolation of attached payloads.



# **Space Structure (Dynamics & Control)**

## **- Consolidation Within Theme -**

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### **Experiment Groupings (Continued):**

- **Space Structures Construction & Control**

- 2061 Large Space Structures
- 2062 Space Station Modifications
- 2064 Advanced Antenna Assembly and Performance
- 2065 Ion Beam Cold Welding
- 2066 Inflatable Rigidizable Structural Element
- 2422 Thermal Shape Control
- - - - In-Space Actively Controlled Structure
- - - - Environmental Influence on Structural Dynamics
- - - - Array Blanket Zero-G Fold-up

- **Sensors, Actuators & Components**

- 2072 Spacecraft Strain & Acoustic Sensors
- 2431 Advanced Control Device Technology
- 2432 Pointing and Isolation Devices
- - - - Fiber Optic Sensors in Space Applications
- - - - Berthing and Docking Sensor
- - - - Polymeric Materials for Space Mechanisms
- - - - Attitude Control & Energy Experiment

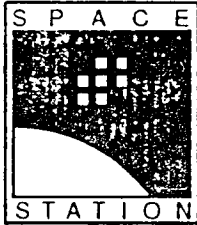
## Space Structure (Dynamics & Control) Consolidation Assessment

Several observations can be made about the experiments in this theme area. First, many of the experiments have already been consolidated by the organizations that proposed them. For example, JPL has defined a series of antenna technology experiments that use the same development hardware. The experiments range from the construction of the antenna to the determination of antenna beam patterns. Other examples include space station dynamics and control experiments that use the space station structure as the test article, and large precision segmented structures experiments that demonstrate techniques for constructing and controlling a precision optical reflector.

Second, some of the smaller experiments can be incorporated into larger experiments for their mutual benefit. The larger experiments would benefit from the inclusion of innovative sensors and actuators, for example, and the priority of the sensor or actuator experiment would be enhanced by being included in the larger experiment.

Third, it is assumed that all satellite assembly and servicing experiments would be conducted within the satellite servicing area that is part of the space station configuration.

One of the conclusions reached as a result of this assessment is that the construction of a large truss platform can accomplish the objectives of several of the proposed experiments (construction of a large planar truss, the dynamic characteristics of a joint dominated structure, space station modifications, etc.). Following its use as a large structures demonstration, the platform can become a permanent space station facility that can be used to accommodate other experiments and multi-experiment testbeds.



# **Space Structure (Dynamics & Controls)**

## **- Consolidation Assessment -**

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### **Observations:**

- Many experiments have already been consolidated.
  - Space Station dynamics & control
  - Antenna experiments
  - Large precision segmented structures
- Smaller experiments (sensors, actuators, etc.) can be incorporated into larger experiments.
- Satellite assembly and testing will occur within the satellite servicing hangar.

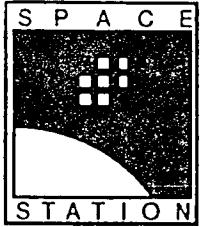
### **Conclusions:**

- A large space structures testbed can accomplish the objectives of several of the remaining experiments.
- Following its use as a structural demonstration, the testbed can be used as a Space Station facility to accommodate other experiments and multi-experiment testbeds.

## Antenna Technology Testbed Experiments

The next two charts show examples of structures experiments that can already be considered testbed candidates.

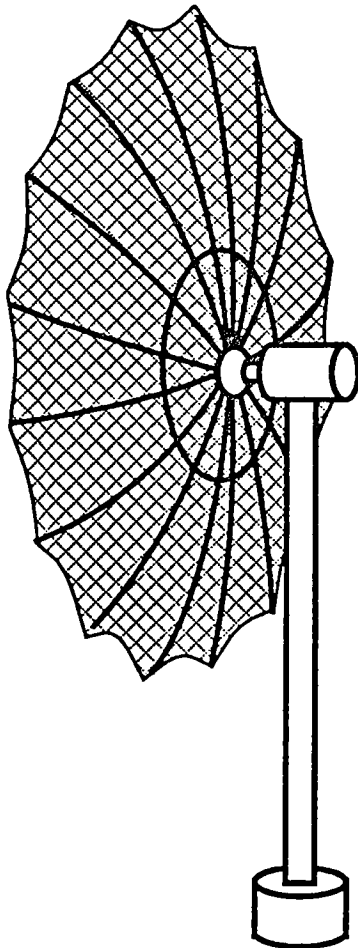
The antenna structure identified by JPL to support a series of antenna experiments can be considered a testbed. Other proposed experiments could also be incorporated. The experiments listed include those that demonstrate the construction of the antenna, that characterize its dynamic behavior, that measure its surface contour, that demonstrate dynamic and figure control techniques, that measure its near-field and far-field characteristics, and that demonstrate space antenna applications.



# Antenna Technology Testbed Experiments

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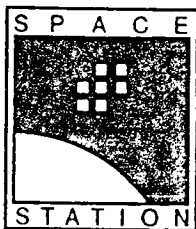
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<u>TDMX</u>	<u>TITLE</u>
2071	Flight Dynamics Identification
2211	Multi-Function Space Antenna Range Technology
2212	Multi Antenna Beam Patterns
2411	Advanced Adaptive Control
2412	Distributed Control Experiment
2413	Dynamic Disturbance Experiment
- - - -	Large Space Antenna (Reflectors)
- - - -	Advanced Orbiting VLBI Technology on the Space Station

## Large Segmented Structures Testbed Experiments

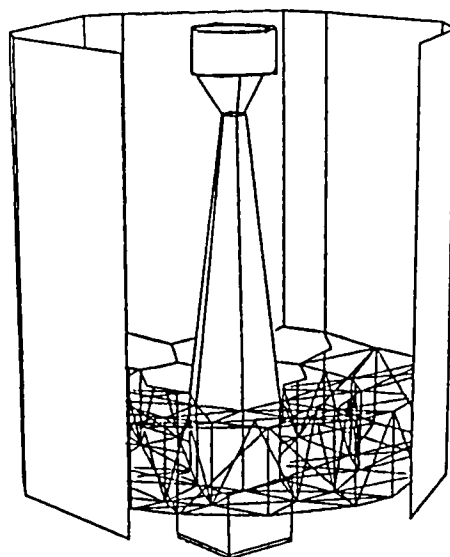
A large precision segmented structures testbed was defined in an earlier task for NASA LaRC. Its primary objective is to demonstrate the technologies required to support the Large Deployable Reflector (LDR). These include the construction of the precision segmented structure and its optics, the characterization of its dynamic behavior, the control of segmented mirror facets, and the operation of optical sensors. The Precision Optical System Assembly experiment listed in this figure uses a different construction technique than currently envisioned for LDR, but includes many of the other technical objectives.



# Large Segmented Structures Testbed Experiments

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<u>TDMX</u>	<u>TITLE</u>
2421	Active Optic Technology
---	Precision Optical System Assembly
---	TDM for LDR

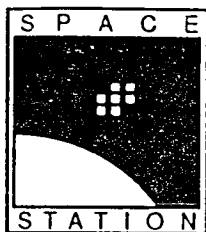




## Large Structures Construction and Servicing Facility

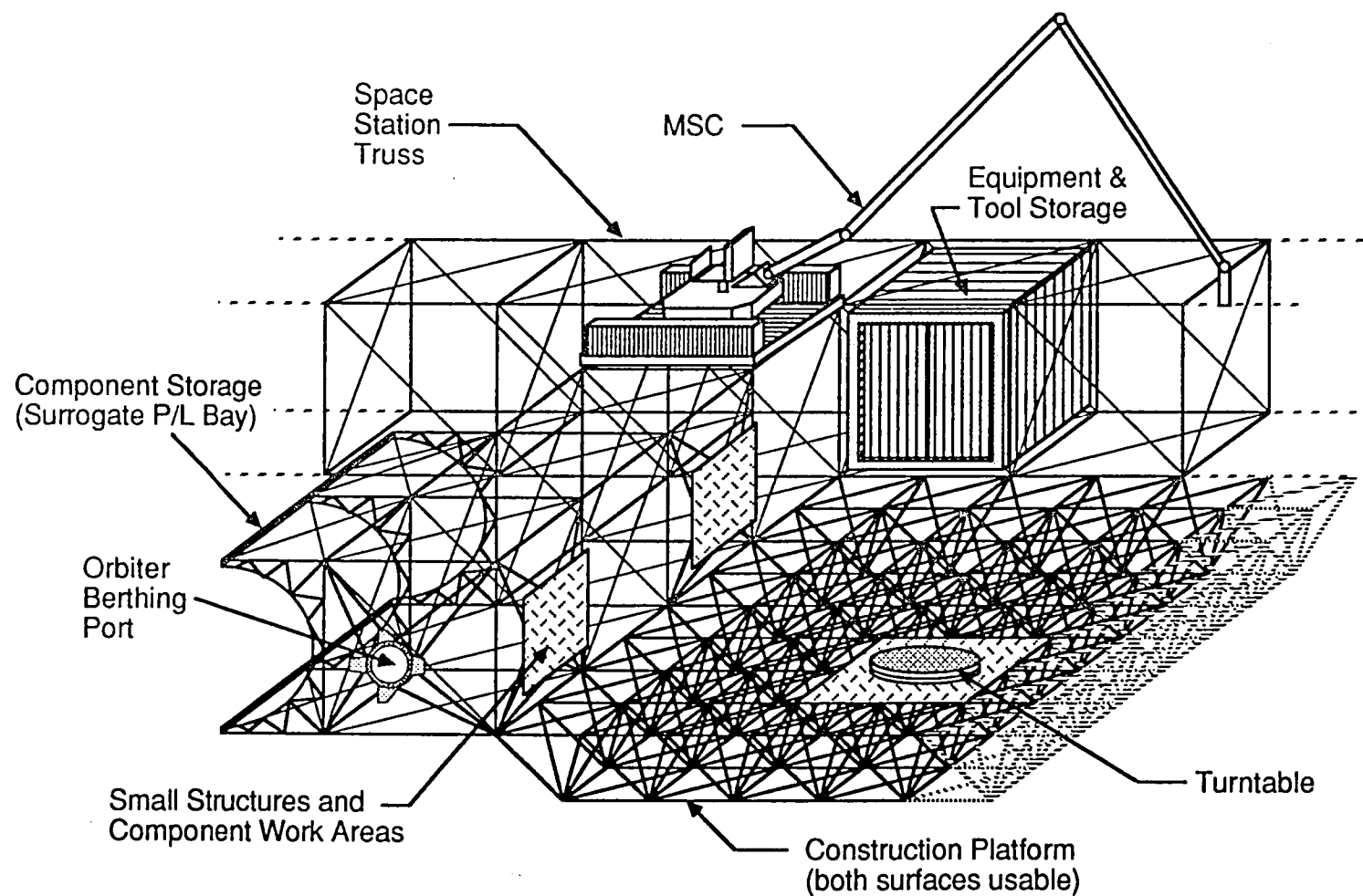
A large space structures experiment is proposed that will become a permanent space station facility following its use as a technology development experiment. It is a refinement of TDMX 2061 that was defined before the space station evolved to its present configuration.

The Large Structures Construction and Servicing Facility is a large structures experiment in itself. It demonstrates the construction of a large planar truss structure and the determination of the dynamic characteristics of a joint dominated structure. It is attached to the space station and provides a large planar area (usable on both surfaces) for other construction projects and demonstration experiments. The facility also includes an enclosed storage hangar for tools and other equipment. A turntable mounted to the truss platform can be used to mount experiments that need to be rotated or indexed during their construction or operation. Small platforms attached to an extension of the space station truss serve as mounting locations for smaller experiments or equipment. A surrogate payload bay structure is attached to the opposite side of the space station truss extension to accommodate pallets and other experiments delivered to the space station by the shuttle. The payload attachment interface is identical to the payload bay longerons. A berthing port is shown in the figure to accommodate the Orbiter during the delivery of experiments to the construction and servicing facility. The feasibility of including the berthing port needs to be investigated due to operational limitations imposed on the location of docking ports on the space station. The Mobile Service Center (MSC) will be capable of supporting experiments mounted on the construction and servicing facility.



# Large Structures Construction & Servicing Facility

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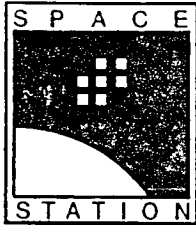
## Objectives of the Large Structures Facility

The primary objectives of the large structures construction and servicing facility are to conduct large space structures technology experiments, to support experiments during its construction, to accommodate technology testbeds, and to provide a location that can accommodate other experiments after it becomes a permanent space station facility. This chart lists the experiments and testbeds that fulfill these objectives. TDMX 2061 is an early version of a Construction/Storage/Hangar Facility proposed in the early phase of space station definition, before it evolved to the double keel configuration. TDMX 2062 is a satellite servicing facility that was proposed in the same timeframe to accommodate satellite servicing. Many of its objectives are satisfied with the large structures facility. The Structural Concepts Research Facility was recommended at the In-Space RT&E Workshop in October, 1985.

The construction of the facility would support the objectives of two man/machine experiments, especially if the facility is robotically assembled.

Five major testbeds can be accommodated by the large structures facility after it becomes a permanent space station facility: automation & robotics, antenna technology, large segmented structures, fluid management, and photovoltaic power generation & management. These testbeds will be discussed in more detail in subsequent charts.

The other individual experiments listed can be conducted from the large structures facility and will benefit from the accommodations, utilities and resources that it can provide.



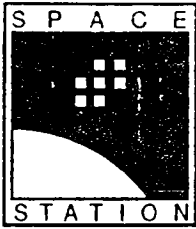
# Objectives of the Large Structures Facility

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<u>Goal</u>	<u>TDMX</u>	<u>Title</u>
LSS Technology	2061	Large Space Structures
	2062	Space Station Modifications
	- - - -	Structural Concepts Research Facility
Support Experiments	2021	Man/Machine Mix Investigations
	2471	Human/Machine Interface Workload
Accommodate Testbeds	- - - -	Automation and Robotics
	- - - -	Antenna Technology Testbed
	- - - -	Large Segmented Structures Testbed
	- - - -	Fluid Management Testbed
	- - - -	Photovoltaic Power Generation & Mgmt. Testbed
Accommodate Other Experiments	2064	Advanced Antenna Assembly/Performance
	2066	Inflatable/Rigidizable Structural Element
	2261	Sensor Systems Technology Experiment
	2422	Thermal Shape Control
	2564	Coatings Maintenance Technology
	- - - -	Berthing & Docking Sensor
	- - - -	In-Space Actively Controlled Structure
	- - - -	Environmental Influence on Structural Dynamics
	- - - -	Helium Transfer in Space
	- - - -	40-105 GHz Propagation Experiment
	- - - -	Solar Array Blanket Zero-G Foldup Experiment
	- - - -	Space Based Radar (SBR)
	- - - -	Space Spider Crane

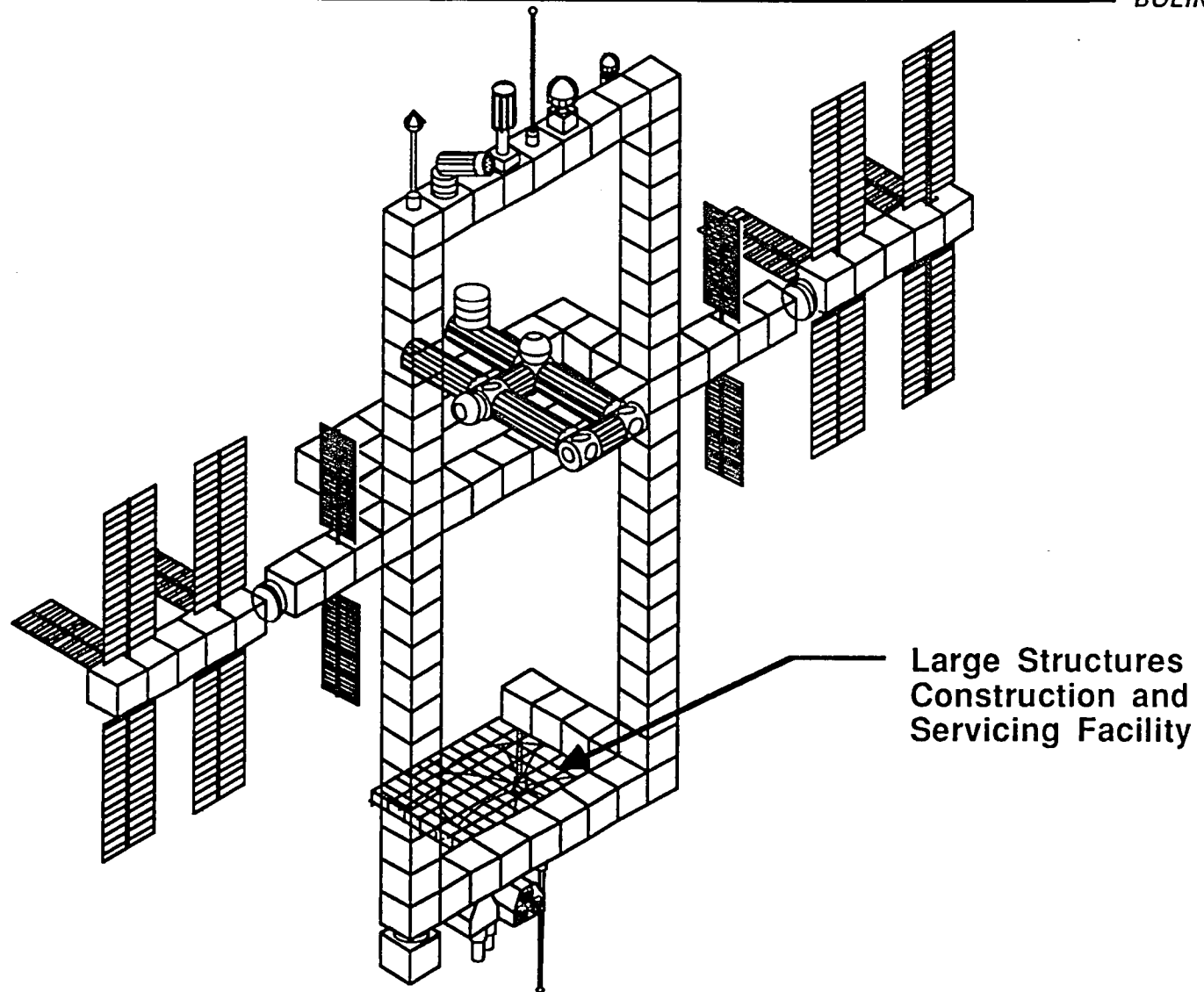
## Large Structures Construction Facility on the Space Station

One possible location for the large structures construction and servicing facility is at the lower transverse boom as shown in the figure. In this position, it would be remote from the pressurized modules, would provide a large volume for the accommodation of large experiments and testbeds, and would also allow viewing to Earth and to space. The location of the facility should be the subject of further study.



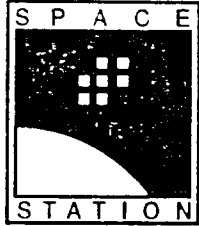
# Large Structures Construction Facility on the Space Station

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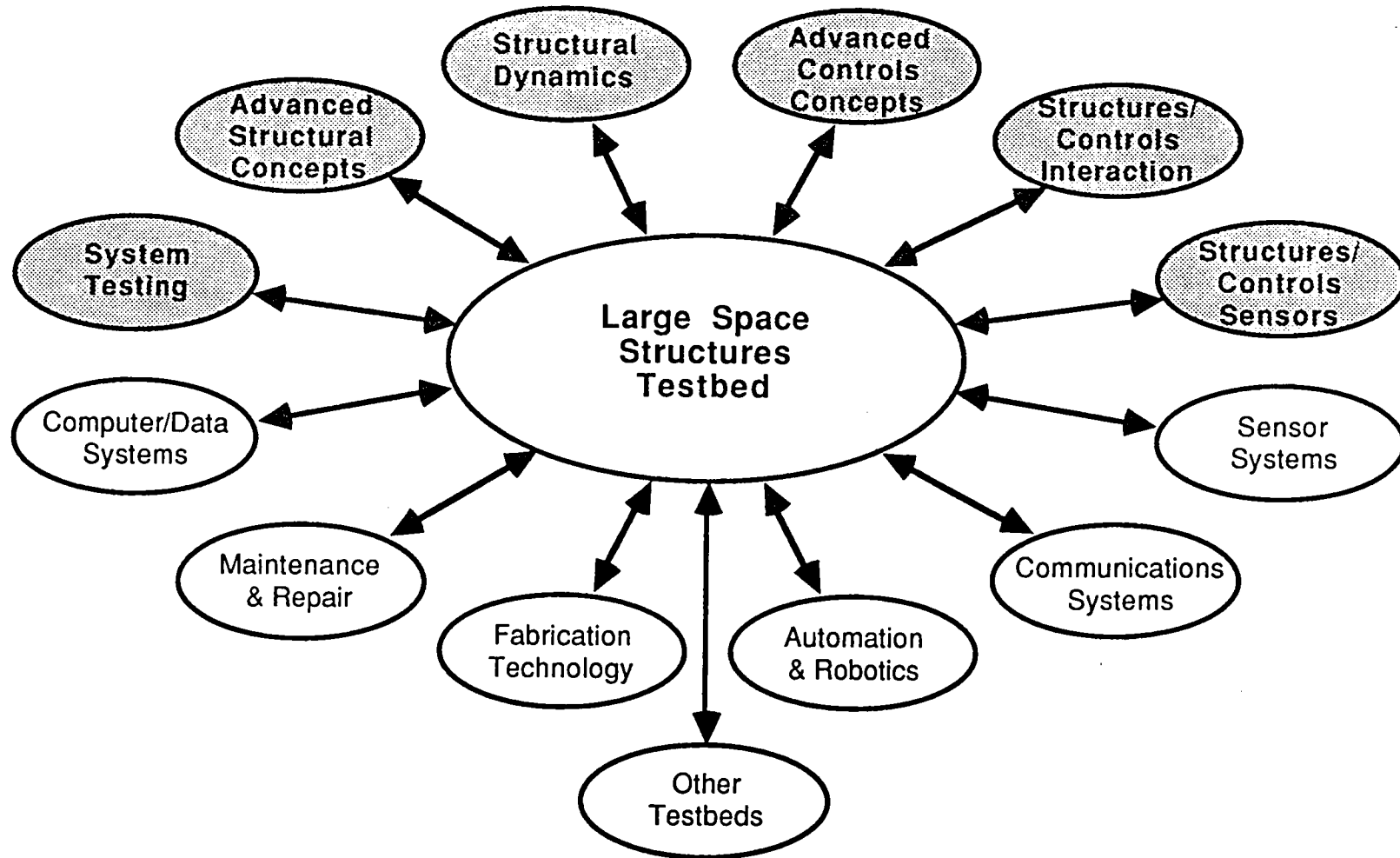
## Technology Areas Supported by the Large Space Structures Testbed

This chart schematically describes the technology areas that would be supported during the construction of the large space structures testbed and following its establishment as a permanent space station facility. Primary technology areas served by the facility are shown as shaded bubbles. Other important technology areas that will be addressed by the facility are shown as unshaded bubbles.



# Technology Areas Supported by the Large Space Structures Testbed

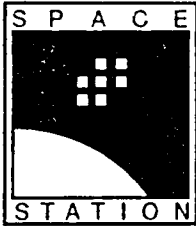
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## General On-Orbit Facilities Requirements, Fluid Management

The primary (bold check marks) and secondary locations for fluid management technology experiments are shown in this chart. Basic research in low-g fluid behavior and measurement can best be done in a laboratory environment within a pressurized module. External facilities are required for large scale experiments and experiments with hazardous fluids. The primary location for fluid storage, transfer and reliquefaction experiments and demonstrations is on an externally attached facility.



# General On-Orbit Facilities Requirements, Fluid Management

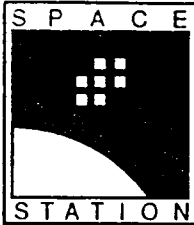
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Experiment Category	Location				Comments
	Internal Press.	External/Attached Press.	Unpress.	Remote	
Fuel Storage & Transfer			✓		External facilities are required. Location should be away from pressurized modules. Should be near or combined with OTV servicing area.
Fluid Behavior	✓		✓		Experiments for determining the dynamic behavior of fluids are best done in a Lab unless fluids or pressures used are too risky. The size of the tanks is also a factor.
Sensor Concepts	✓		✓		Fluid sensor concept experiments can be conducted in a pressurized module using the same tanks used for fluid behavior experiments.

↑  
Area of interest

## Fluid Management Experiments Considered

This chart lists fluid management experiments included in the Mission Requirements Data Base (MRDB) and those that were proposed at the RT&E workshop. The experiments identified as representative of experiments that would occur in the three years following space station IOC are marked with an asterisk.



# Fluid Management

## - Experiments Considered -

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### TDMX

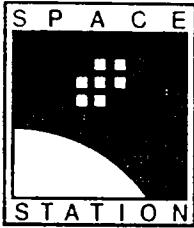
### TITLE

2311*	Long-term Cryogenic Fluid Storage
2544	Tethered Fluid Storage/Transfer
2572*	Cryogenic Propellant Transfer/Storage/Reliquefaction
- - - -	Helium Resupply Kit
- - - -	Liquid Stream Space Technology Facility
- - - -	Ultrasonic Fluid Measurement
- - - -	Two Phase Fluid Management for Liquid Metals

\* IOC Timeframe

## Cryogenic Fluid Management Facility (CFMF) Experiment

The CFMF was originally planned as a space shuttle experiment, but, as a result of the Challenger accident, NASA established a policy that prevents the delivery of cryogenic fluids in the cargo bay. Therefore, the current plan is to deliver the CFMF (now called CFME, Cryogenic Fluid Management Experiment) to orbit with a Delta booster in late '94. The planned duration of CFME is two years, which will overlap the current date for space station IOC. With proper design and careful planning, the CFME could be continued beyond its planned duration by retrieving it and attaching it to the space station. This would allow fluid management experimentation and research to continue without additional experiment hardware development costs.



## **Cryogenic Fluid Management Facility (CFMF) Experiment**

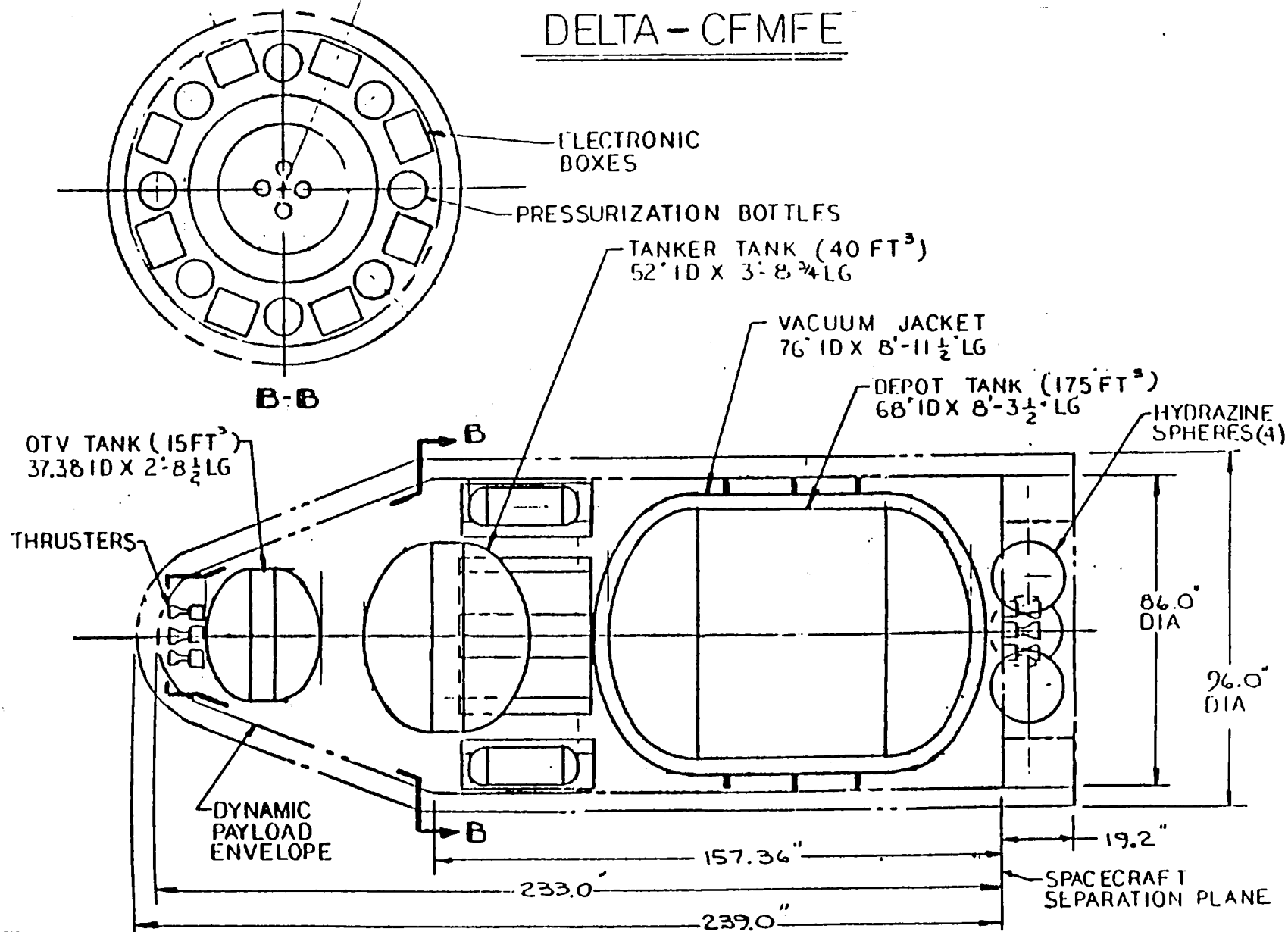
*BOEING*

- **LeRC will release a definition phase RFP worth \$2M in June '87.**
- **CFMF is currently planned as a free-flyer launched with a Delta booster to an orbit similar to that for the Space Station.**
- **Launch is scheduled for late CY94 with a 2-year life (overlaps Space Station IOC).**
- **Precise CFMF definition depends on user community requirements:**
  - **Tank sizing and shape**
  - **Refrigeration system requirement**
  - **With the addition of a grapple fixture, CFMF could rendezvous with the Station for modification and/or captive testing after a year of free-flight.**

## Delta - CFME

This figure shows a preliminary configuration for the Cryogenic Fluid Management Experiment (CFME) designed to be delivered to low Earth orbit by a Delta booster.

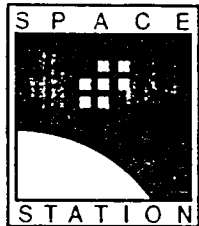
DELTA - CFMFE





## Fluid Management Consolidation Within Theme

Fluid management experiments fall into two categories: cryogenic fluid experiments and basic fluid research. Experiments using cryogenic fluids of several types are proposed but may not be able to use the same facility due to disparate liquefaction temperatures, molecule size, and chemical activity. Fluids research experiments include the behavior and management of free fluid streams in space, the measurement of tanked fluids in a micro-g environment, and the management of liquid metals.



# **Fluid Management**

## **- Consolidation Within Theme -**

**BOEING**

### **Experiment Groupings:**

- **Cryogenic Fluid Management**

- 2311 Long-term Cryogenic Fluid Storage**

- 2544 Tethered Fluid Storage/Transfer**

- 2572 Cryogenic Propellant Transfer/Storage/Reliquefaction**

- - - - Helium Resupply Kit**

- **Fluids Research**

- - - - Liquid Stream Space Technology Facility**

- - - - Ultrasonic Fluid Measurement**

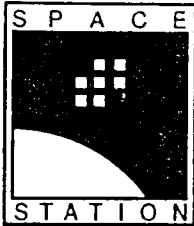
- - - - Two Phase Fluid Management for Liquid Metals**

## Fluid Management - Consolidation Assessment General Observations

Some general observations concerning the proposed fluid management experiments are listed in this figure.

Many of the experiments are defined as space station experiments, most of which are externally attached. One is designed as a tethered experiment. With the restriction imposed on cryogenics in the Orbiter cargo bay, some of the experiments envisioned as shuttle experiments could be conducted on the space station if an alternate delivery system is used. The experiments could be designed to be attached to the space station using a surrogate payload bay facility or one that accommodates the mounting provisions dictated by the delivery system.

Fluid management experiments are important because the technology is required by the space station, orbital maneuvering vehicle (OMV), orbital transfer vehicle (OTV), and other future satellites. Some fluid management technology goals will be satisfied by the CFMF (or CFME).



# Fluid Management - Consolidation Assessment -

BOEING

## General Observations:

- Both Space Station attached and tethered experiments are defined.
- NASA has edicted "no cryos in the Orbiter cargo bay"
- Some experiments are defined as Orbiter-based, but may be applicable for Space Station experiments.
- Some fluid management experiment facilities can be attached to a surrogate payload bay on the Space Station.
- Low-G fluid management technology is required for OMV, OTV, Space Station and other satellites.
- The LeRC CFMF duplicates many of the defined experiments.

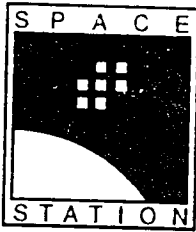
## Fluid Management - Consolidation Assessment Specific Observations

This chart lists some specific observations relative to the three fluid management TDMX experiments.

The long term cryogenic fluid storage experiment, TDMX 2311, will need to be redefined in light of the restrictions on cryogenic fluids in the shuttle cargo bay. The supply tank and receiver tank sizes are similar to the CFMF. Active refrigeration is required in the third phase of the experiment. Its objectives are also similar to TDMX 2572.

The tethered fluid storage/transfer experiment, TDMX 2544, as described in the MRDB is extremely large (35,000 kg), and is too large to be considered an experiment. A smaller facility would be adequate for the demonstration of tethered fluid management technology.

TDMX 2572, Cryo Propellant Transfer/Storage/Reliquefaction, must also be redefined in light of the cryogenic fluid restrictions in the cargo bay. The dimensions of its supply tank and receiver tank are significantly larger than those defined for CFMF. Also, the objectives of this experiment are similar to TDMX 2311 and CFMF.



# Fluid Management

## - Consolidation Assessment -

BOEING

### Specific Observations:

- TDMX 2311- Long-term Cryogenic Fluid Storage
  - Must be redefined in view of "no-cryo" edict
  - Supply and receiver tank sizes similar to current CFMF
  - Phase III calls for the addition of active refrigeration system
  - Objectives are similar to TDMX 2572 and CFMF
- TDMX 2544 - Tethered Fluid Storage/Transfer
  - At 35,000 kg (~ 77,000 lbm) it is too large to be called an experiment.
  - The pedigree of the experiment cannot be established.
    - The MSFC point of contact has retired
    - The MMC study for JSC recommended a 128,000 lbm system for full scale operation of a propellant depot.
- TDMX 2572 - Cryo Propellant Transfer/Storage/Reliquefaction
  - Must be redefined in view of "no cryo" edict
  - Supply tank size is roughly twice that of current CFMF and receiver is roughly four times bigger
  - Objectives are very similar to TDMX 2311 and CFMF

## Fluid Management - Consolidation Assessment Conclusions

The conclusions reached as a result of the consolidation assessment are shown on the next two charts.

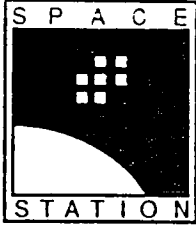
The goals and requirements of TDMX 2311 and TDMX 2572 are similar and, therefore, should be combined. They will also need to be redefined in light of the shuttle cryo restrictions. The feasibility of expanding CFMF to satisfy the requirements of these experiments should be investigated. If it is properly designed, CFMF could be retrieved, attached to the space station, and used as a technology development experiment after its initial testing as a free-flyer.

A space-based OTV using cryogenic propellants is very unlikely to become a reality in this century, and probably not before 2010, unless an urgent need appears that would increase its priority. Therefore, TDMX 2544 should be redefined because its size is larger than necessary to demonstrate tethered fluid storage and transfer. Many of the goals identified for this experiment can be examined more effectively by TDMX 2311, TDMX 2572 and CFMF. Also, the technology associated with tethered fluid storage and transfer operations should be studied using non-cryogenic fluids initially.

Consolidation of experimental hardware can be achieved if the cryogenic fluid management experiment is designed to be used both as an attached experiment and as a tethered experiment. If possible, the attached experiment should be located near the OMV or OTV servicing area.

With the exception of the liquid metals experiment, initial experiments in fluid behavior and measurement should be conducted in a laboratory module to permit human interaction during the investigations.

The two phase liquid metal management experiment should be combined with the experiments in the Power and Thermal Management Theme area since this technology is used in solar dynamic power generation.



# Fluid Management

## - Consolidation Assessment -

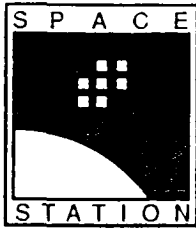
BOEING

### Conclusions:

- TDMX 2311 - Long-term Cryogenic Fluid Storage & TDMX 2572 - Cryo Propellant Transfer/Storage/Reliquefaction
  - As a minimum, redefine and combine
  - Investigate the feasibility of expanding CFMF to satisfy the requirements of these experiments
- TDMX 2544 - Tethered Fluid Storage/Transfer
  - Should be redefined considering:
    - The size appears to be much larger than required for the physics involved.
    - Much of the technology called out can be examined more effectively by TDMX 2311, 2572 or CFMF.
    - The technology associated with tethered operation should first be studied using non-cryo fluids.
    - A space-based cryo OTV is very unlikely to occur in this century and probably not before 2010 unless needs change drastically.







# **Fluid Management - Consolidation Assessment -**

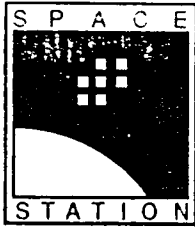
**BOEING**

## **Conclusions (Continued):**

- **Design applicable cryogenic fluid management experiment to be adaptable for tether operation.**
- **Locate attached cryogenic experiments in or near the OTV and/or OMV servicing areas.**
- **Fluids research experiments should initially be conducted within a Lab Module (with the possible exception of the liquid metals Experiment).**
- **Two phase fluid management for liquid metals experiment should be combined with Power and Thermal Management Theme experiments.**

## Fluid Management Testbed

The experiment shown in this figure is the proposed configuration for TDMX 2311, Long-term Cryogenic Fluid Storage, and represents a possible testbed for fluid management technology development. It was configured for delivery by the space shuttle and, therefore, could be attached to the space station using a surrogate payload bay mounting system. It will, however, need to be modified to be accommodated by an alternate delivery system if the shuttle restrictions on cryos continues. More than one testbed may be required to accommodate the characteristics of different cryogenic fluids.



# Fluid Management Testbed

BOEING

TDMX

TITLE

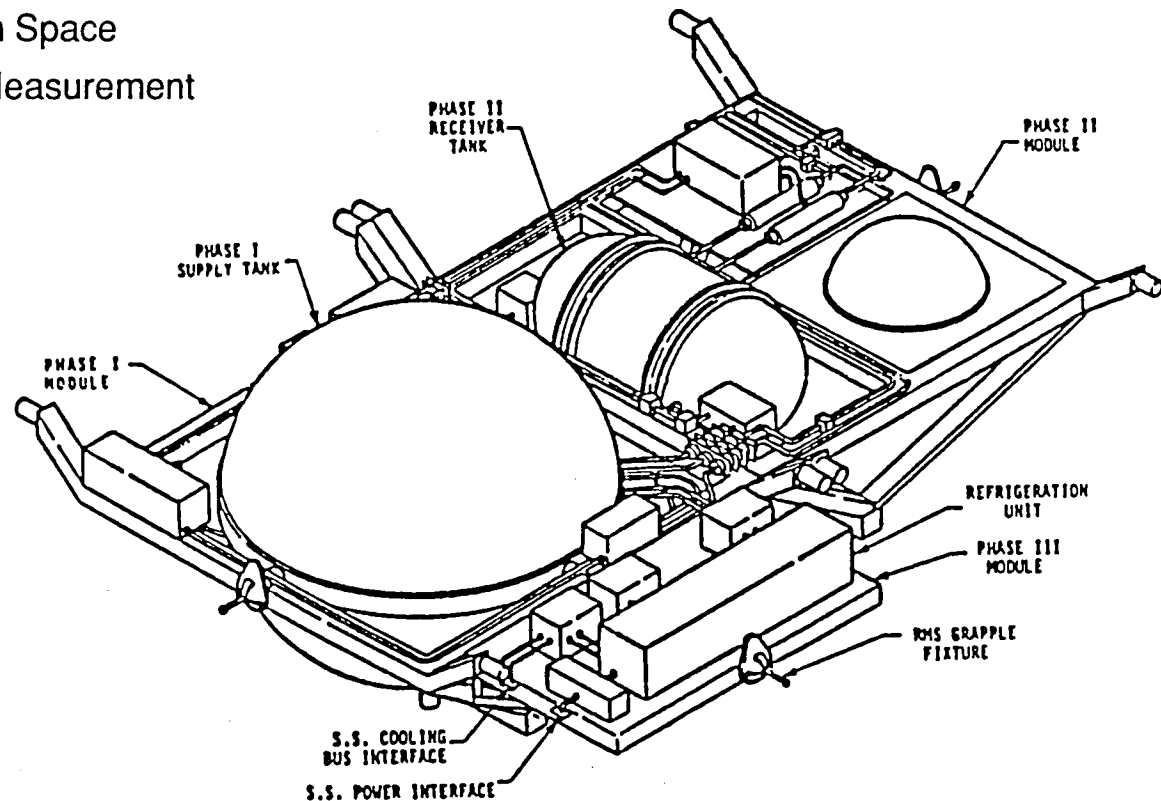
2311 Long-term Cryogenic Fluid Storage

2544 Tethered Fluid Storage\Transfer

2572 Cryogenic Propellant Transfer/Storage/Reliquefaction

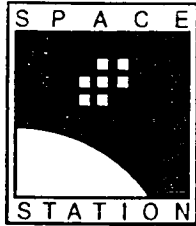
---- Helium Transfer in Space

---- Ultrasonic Fluid Measurement



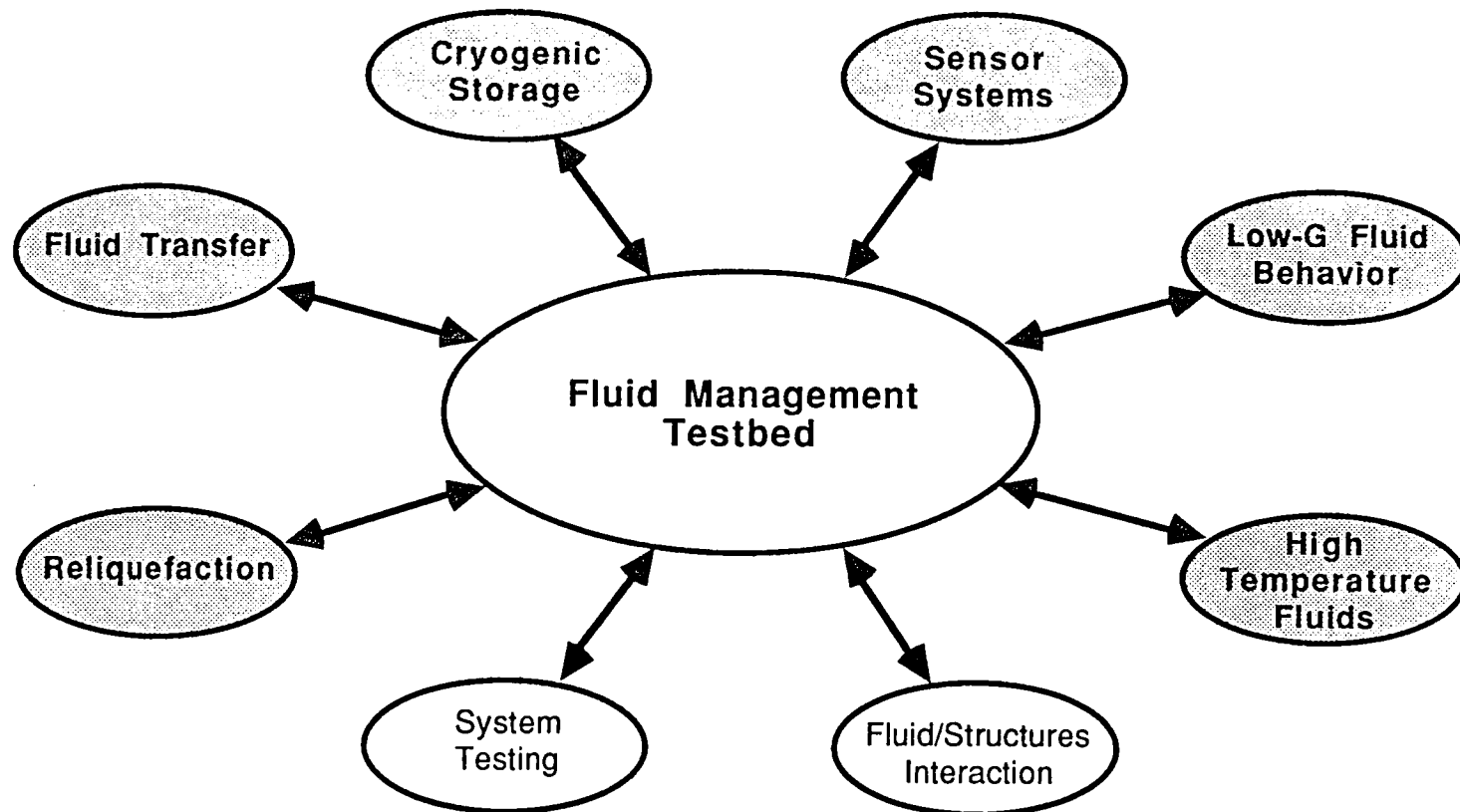
## Technology Areas Supported by the Fluid Management Testbed

This chart depicts the technology areas that would be developed using the fluid management testbed. The primary areas, shown in the shaded bubbles, deal with the management of fluids in space, and the areas in the unshaded bubbles represent secondary technology results that would be enhanced by this testbed.



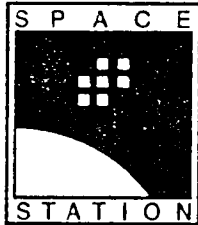
# Technology Areas Supported by the Fluid Management Testbed

BOEING



## General On-Orbit Facilities Requirements Space Environmental Effects

Experiment categories within the Space Environmental Effect Theme Area are listed in this figure along with the types of facilities required. All of the experiments dealing with the measurement of the space environment and those that expose materials to the space environment require externally mounted facilities. An exception to this is the testing of some electronic systems (not considered in this study) that are mounted inside a pressurized module. Testing and evaluation of the exposed material samples requires a pressurized laboratory, or they must be returned to Earth.



# General On-Orbit Facilities Requirements, Space Environmental Effects

BOEING

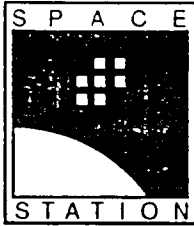
Experiment Category	Location			Remote	Comments
	Internal Press.	External/Attached Press.	Unpress.		
Material Durability Atomic Oxygen Ultraviolet/Vacuum Electron/Proton	✓		✓		External facilities are required for materials exposure using several different exposure orientations and locations. Pressurized Lab is required for evaluation of samples.
Plasma	✓		✓		External facilities are required for materials exposure. Pressurized Lab is required for evaluation of samples.
Contamination	✓		✓		External facilities are required for materials exposure. Pressurized Lab is required for evaluation of samples.

Area of interest



## Space Environmental Effects Experiments Considered

The externally mounted environmental effects experiments from the NASA Mission Requirements Data Base (MRDB) and the RT&E Workshop are listed in this figure. The experiments marked with an asterisk are representative of experiments that will be conducted within the first three years following space station IOC.



# Space Environmental Effects - Experiments Considered -

BOEING

## TDMX

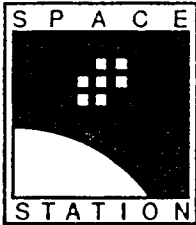
## TITLE

2011*	Spacecraft Materials and Coatings
2441*	Microelectronics Data System Experiment
- - - -	Atomic Oxygen Effects Experiment
- - - -	40-105 GHz Propagation Experiment
- - - -	Space Ultra-Vacuum Facility (Wake Shield)
- - - -	Environmental Interactions

\* IOC Timeframe

Space Environmental Effects  
Consolidation Within Theme

Space environmental effects experiments can be grouped into two categories: those that study the effects of the natural environment on materials and systems, and those that determine the induced effects resulting from the introduction of objects or the transmission of signals.



# **Space Environmental Effects - Consolidation Within Theme -**

**BOEING**

## **Experiment Groupings:**

- **Natural Environmental Effects**

- 2011 Spacecraft Materials and Coatings**

- 2441 Microelectronics Data System Experiment**

- - - - Atomic Oxygen Effects Experiment**

- **Induced Environmental Effects**

- - - - 40-105 GHz Propagation Experiment**

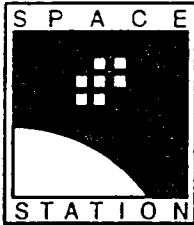
- - - - Space Ultra-Vacuum Facility (Wake Shield)**

- - - - Environmental Interactions**

## Space Environmental Effects Consolidation Assessment

A review of the candidate experiments in the Space Environmental Effects theme area reveals the observation that they require a variety of exposure orientations and that they have unique hardware requirements. For example, the materials and coatings experiments require wake facing, velocity facing and solar facing orientations. Another observation is that the "Environmental Interactions" experiment relates primarily to the influence of the low Earth orbit environment on power system components. Therefore, one of the conclusions reached is that this experiment should be combined with those within the Energy and Thermal Management theme area.

Because of the diverse equipment and exposure requirements, consolidation of the other experiments is not practical. Some commonality, however, can be designed into the exposure trays and support structure for the materials and coatings, and atomic oxygen effects experiments.



# **Space Environmental Effects - Consolidation Assessment -**

*BOEING*

## **Observations:**

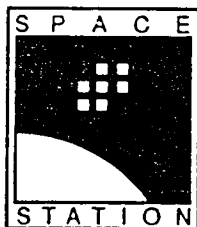
- **Exposure experiments require a variety of orientations.**
- **Most experiments have unique equipment requirements.**
- **"Environmental Interactions" experiment relates to power systems**

## **Conclusions:**

- **Integrate "Environmental Interactions" experiment with Energy and Thermal Management theme.**
- **Consolidation of space environmental effects experiments is not practical (other than using a common design for the exposure trays and support structure).**

## General On-Orbit Facilities Requirements Energy Systems and Thermal Management

The energy systems and thermal management experiments were categorized in terms of their location during operation. All of the experiments are required to be mounted externally to the space station or on a remote platform or free-flyer. Potential risks associated with laser technology and nuclear power technology make them candidates for remote locations.



# General On-Orbit Facilities Requirements, Energy Systems & Thermal Management

BOEING

Experiment Category	Location			Remote	Comments
	Internal Press.	External/Attached Press.	Unpress.		
Advanced Photovoltaics			✓		External facilities are required.
Solar Dynamics			✓		External facilities are required.
Advanced Thermal Concepts			✓		External facilities are required. Since all power experiments need radiators, it is logical to combine power generation facilities with thermal research facilities.
Nuclear Power				✓	A remote, external facility is required, possibly a co-orbiting facility, due to the potential risks.
Laser Power				✓	Remote facilities will probably be required for laser technology .

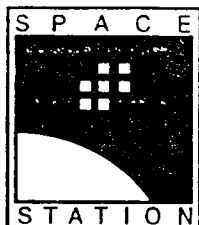


Area of interest



## Energy Systems and Thermal Management Experiments Considered

This chart lists the externally mounted experiments in the energy and thermal management theme area as described in the MRDB or as proposed at the RT&E workshop. Abbreviated names were assigned to those that do not already have TDMX numbers to identify them. Experiments that are representative of near IOC experiments are identified with an asterisk. Laser technology and nuclear energy technology experiments are not included in this list. Although TDMX 2111, Solar Concentrator, is proposed as the first in a series of laser experiments, it is retained in this list because other energy system experiments require a solar concentrator.



# Energy Systems & Thermal Management - Experiments Considered -

BOEING

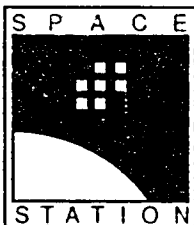
<u>TDMX</u>	<u>TITLE</u>
2111	Solar Concentrator
2131	Radiator Technology
2132*	Advanced Radiator Technology
2151	Solar Array/Energy Storage Technology
2152	Large Space Power Systems Technology
2153* <sup>1</sup>	Solar Dynamic Power
2154	Megawatt Power Distribution
2511	Space Power System Environment Interference
2512	High Voltage in Space Plasma
2541	Tethered Electrodynamic Power Generation
2565	Thermal Interface Technology
DSTF	Direct Solar Thermal Furnace Technology
ABZF	Array Blanket Zero-G Fold-up
FBTM	Flow Boiling Thermal Management
ENVI	Environmental Interaction Experiment

<sup>1</sup> Series - Brayton, Stirling and Rankine Systems

\* IOC Timeframe

## Energy Systems and Thermal Management Requirements Summary

The energy systems and thermal management experiments are categorized by their requirements in this table. Most of the experiments require solar tracking, radiation to space and crew involvement. Many of the experiments also identify the requirement to design the experiment such that it does not interfere with the space station power management and distribution (PMAD) system.



# Energy Systems & Thermal Management - Requirements Summary -

BOEING

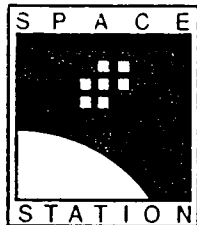
REQUIREMENTS	EXPERIMENTS														
	2111	2131	2132	2151	2152	2153	2154	2511	2512	2541	2565	DSTF	ABZF	FBTM	ENVI
Two-Axis Solar Tracking	X		X <sup>2</sup>	X	X	X	X <sup>1</sup>		X			X			
Radiation to Space	X	X	X	X	X	X	X <sup>1</sup>					X		X	
Concentrator Focused Energy	X					X						X			
Electric Heating			X								X			X	
Non-interference/S.S. PMAD	X		X	X	X	X						X			
Crew Deployment	X	X	X	X	X	X	X	X		X	X	X	X	X	X
Crew Servicing	X							X			X	X		X	

1 Uses Space Station Power Systems

2 Keeps Low Profile to Sun

## Energy Systems and Thermal Management Consolidation Within Theme

A review of the energy systems and thermal management experiments and their requirements revealed that their primary objectives fall into one of four general categories: those that track the sun for heat generation, those that generate power, those that radiate heat, and those that study the effects of the environment on power systems. Each of these categories are discussed in more detail in the following charts.



# **Energy Systems & Thermal Management**

## **- Consolidation Within Theme -**

**BOEING**

### **Experiment Groupings:**

- **Solar Tracking for Heat**
- **Power Generation**
- **Thermal Management**
- **Phenomenological Investigations**

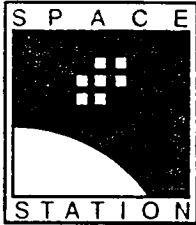
## Energy Systems and Thermal Management Solar Tracking for Heat

The candidate experiments that require solar tracking for heat are:

- TDMX 2111 - Solar Concentrator
- TDMX 2153 - Solar Dynamic Power
- DSTF - Direct Solar Thermal Furnace

All of these experiments require two-axis solar tracking, the concentration and utilization of heat, and the rejection of surplus heat to space.

The common elements for these experiments are parabolic concentrators to collect the solar energy, focal point inserts to utilize the heat collected, and radiators to reject the surplus heat.



# **Energy Systems & Thermal Management. Solar Tracking for Heat**

---

*BOEING*

## **Candidates:**

- 2111 - Solar Concentrator**
- 2153 - Solar Dynamic Power**
- DSTF - Direct Solar Thermal Furnace**

## **Common Requirements:**

- Two-Axis Solar Tracking**
- Heat Concentration/Utilization**
- Heat Rejection to Space**

## **Common Elements:**

- Parabolic Concentrators**
- Focal Point Inserts**
- Radiators**



Energy Systems and Thermal Management  
Solar Tracking for Heat (continued)

This chart lists several considerations and observations that resulted from an assessment of the candidate experiments.

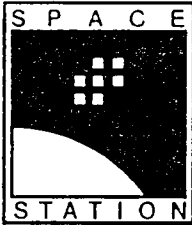
As currently proposed, the Solar Concentrator experiment, TDMX 2111, is a fixed parabolic concentrator, and the solar energy is reflected into it using a heliostat that tracks the sun. However, the technology required to construct a parabolic concentrator is common to the other experiments in this category. TDMX 2153 and DSTF have similar general configuration requirements, i.e., concentrator and radiator.

The sizes of the concentrators for these experiments are different, so separate concentrators must be used, a compromise must be reached to achieve commonality, or an iris-type system is needed to adjust the effective reflector area.

Crew interaction is required for the assembly and installation of focal point inserts. More crew involvement is needed for the direct solar thermal furnace (DSTF) because of the requirements for target sample retrieval and replacement.

The current requirement for TDMX 2153, Solar Dynamic Power, is to have seven years of continuous operation. Therefore, the development hardware cannot be shared by other experiments.

It is recommended that two different experiments be developed for Energy Systems and Thermal Management, one for TDMX 2153, Solar Dynamic Power, and one for the Direct Solar Thermal Furnace.



# **Energy Systems & Thermal Management.**

## **Solar Tracking for Heat**

**BOEING**

### **Considerations -**

#### **Configuration:**

- 2111 Solar Concentrator fixed, heliostat tracks sun, designed for laser power experiments
- Candidates 2153 and DSTF have the same general configuration of concentrator and radiator.

#### **Size:**

- Concentrators, radiators have disparate sizes, so the same concentrator cannot be used, or a compromise is required.

#### **Crew Requirements:**

- Installation requirements similar for 2153 & DSTF
- More servicing expected on DSTF (Furnace)

#### **Time Phasing:**

- 2153 requires 7 years of continuous operation

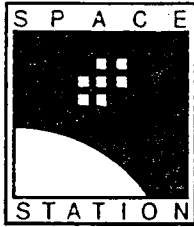
### **Recommendations -**

- Utilize one location (testbed) for 2153 - Solar Dynamic Power.
- Utilize separate location for DSTF - Direct Solar Thermal Furnace

## Energy Systems and Thermal Management Power Generation

The candidate experiments for Power Generation are shown on this chart. TDMX 2151 utilizes the electrical energy from solar arrays to create oxygen and hydrogen through the electrolysis of water or to drive an inertial energy storage device. TDMX 2152 studies the generation, distribution and management of power using planar photovoltaic solar arrays and concentrator photovoltaic arrays. These experiments require devices for two axis solar tracking and must not interfere with the space station power management and distribution (PMAD) system. TDMX 2154 demonstrates both AC and DC megawatt power management in space. The array blanket zero-g fold-up experiment demonstrates the deployment of a fold-up solar array structure.

The common elements in these experiments are the solar arrays or concentrator arrays and, except for the array blanket zero-g fold-up experiment, power management, distribution and energy storage units.



# **Energy Systems & Thermal Management. Power Generation**

**BOEING**

## **Candidates:**

**2151 - Solar Array/Energy Storage Technology**

**2152 - Large Space Power System Technology**

**2154 - Megawatt Power Distribution**

**ABZF- Array Blanket Zero-G Fold-up**

## **Common Requirements:**

**Two-Axis Solar Tracking**

**Non-interference with Space Station PMAD for 2151, 2152**

## **Common Elements:**

**Solar Array/Concentrator**

**Power Management and Distribution Units**

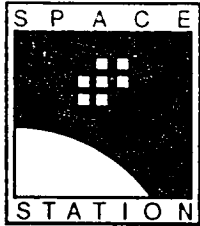
**Energy Storage Units**

Energy Systems and Thermal Management  
Power Generation  
Considerations & Recommendations

As currently envisioned, the Megawatt Power Distribution experiment (TDMX 2154) uses space station thermal radiators and a large amount of space station power. In fact, the experiment uses almost all of the power generated by the space station for short periods of time. The other power experiments must be designed so that there is no interference with the space station power management and distribution (PMAD) system, i.e., no danger of arcing or otherwise corrupting space station power.

The objective of the Array Blanket Zero-G Fold-up experiment is primarily to demonstrate structural and functional aspects of solar array deployment.

It is recommended that TDMX 2151, Solar Array/Energy Storage Technology, and TDMX 2152, Large Space Power Systems Technology, be combined into one testbed. Its preferred location is on the power boom, outboard of the alpha joint to eliminate one of the pointing axes. Otherwise it should be located at a point that is in clear view of the sun, e.g. the upper transverse boom.



# **Energy Systems & Thermal Management. Power Generation**

**BOEING**

## **Considerations -**

- **2154, Megawatt Power Distribution Experiment, uses Space Station power arrays and radiators**
- **Other power experiments are to be non-interfering with Space Station power system (e.g., no common slip joint wiring, no arcing danger)**
- **Array Blanket Zero-G Fold-up is a structural deployment exp.**

## **Recommendations -**

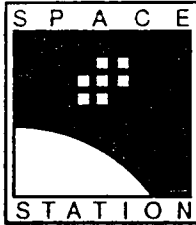
- **Utilize one location (testbed) for:**
  - **2151 - Solar Array/Energy Storage Technology**
  - **2152 - Large Space Power Systems Technology**
- **Preferred locations are upper transverse boom or end of power boom - decision based on IOC configuration, potential of high voltage arcing and/or interference with Space Station PMAD**

## Energy Systems and Thermal Management Thermal Management

Candidate experiments for thermal management include three that are in the Mission Requirements Data Base and one that was proposed at the RT&E Workshop. TDMX 2132 deals primarily with the technology involved in the thermal behavior of free fluid streams in space, e.g., liquid droplet radiators. TDMX 2565 studies the quality of thermal interfaces between exchangeable equipment and the cold plate that they are mounted on. The Flow Boiling Thermal Management experiment establishes a data base for two-phase flow and heat transfer in microgravity.

In looking for ways to consolidate technology development experiments, it is observed that many power and thermal energy experiments require radiators for thermal control. Therefore, it is recommended that thermal control experiments be consolidated with power generation and thermal energy experiments. A radiator of proven quality and reliability must also be provided to insure adequate thermal management at all times.

Another consideration is that the Advanced Radiator Technology experiment that utilizes exposed fluids must be kept separated from the space station to prevent potential contamination from free-flying fluid streams or droplets.



# **Energy Systems & Thermal Management.**

## **Thermal Management**

---

BOEING

### **Candidates:**

- 2131 - Radiator Technology**
- 2132 - Advanced Radiator Technology (exposed fluids)**
- 2565 - Thermal Interface Technology**
- FBTM- Flow Boiling Thermal Management**

### **Other Experiments Utilize Radiators:**

- 2151 - Solar Array/Energy Storage Technology**
- 2152 - Large Space Power Systems Technology**
- 2153 - Solar Dynamic Power**
- 2154 - Megawatt Power Distribution (Station Radiators)**
- DSTF - Direct Solar Thermal Furnace Technology**

### **Considerations:**

**2132 - Advanced Radiator Technology experiments must be kept separate from other experiments due to potential contamination.**

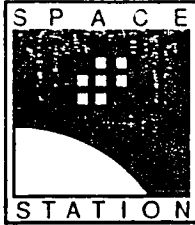
**2131 could be employed on many other experiments with reliable back-up radiator, or could be part of 2132, depending on temperature ranges used.**



## Energy Systems and Thermal Management Phenomenological Investigations

This chart lists candidate experiments that explore the influence of the space environment on the generation and distribution of electrical power.

A review of these experiments reveals similarities between the TDMX 2511 - Space Power System Environment Interference, TDMX 2512 - High Voltage in Space Plasma, and ENVI - Environmental Interactions Experiment. The potential difference is in the voltages used in each experiment. As proposed, TDMX 2511 is intended to be combined with TDMX 2152, Large Space Power Systems Technology. The duration proposed for TDMX 2512 is five years.



# **Energy Systems & Thermal Management. Phenomenological Investigations**

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*BOEING*

## **Candidates:**

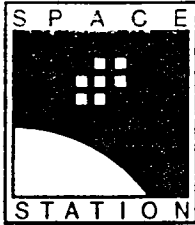
- 2511 - Space Power System Environment Interference**
- 2512 - High Voltage in Space Plasma**
- ENVI - Environmental Interactions Experiment**

## **Considerations:**

- 2511, 2512 and ENVI are similar (may be voltage differences)**
- 2511 is intended to be combined with 2152**
- 2512 is a 5 year experiment**

## Energy Systems and Thermal Management Recommended Testbeds

As a result of the preceding observations and recommendations, two technology development testbeds are recommended for the Energy Systems and Thermal Management theme area: one for thermal energy generation and management, and one for photovoltaic power generation and management. The Thermal Energy Generation and Management Testbed also includes experiments that demonstrate radiator technology (e.g., TDMX 2131). The Photovoltaic Power Generation and Management Testbed combines power generation, energy management, environmental influence, and radiator technology experiments.



# Energy Systems & Thermal Management. Recommended Testbeds

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## 1. Thermal Energy Generation & Management

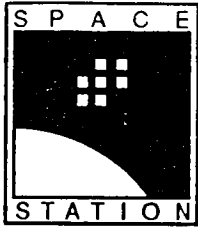
- 2153 - Solar Dynamic Power
  - Brayton Cycle System
  - Stirling Engine
  - Rankine Cycle System
- 2131 - Radiator Technology
- 2565 - Thermal Interface Technology

## 2. Photovoltaic Power Generation and Management

- 2151 - Solar Array/Energy Storage Technology
- 2152 - Large Space Power Systems Technology
- 2511 - Space Power System Environment Interference
- 2512 - High Voltage in Space Plasma
- ENVI - Environmental Interaction Experiment
- 2131 - Radiator Technology
- 2565 - Thermal Interface Technology

## Thermal Energy Generation & Management Testbed

This figure shows a candidate configuration for the Thermal Energy Generation and Management Testbed. It incorporates a two-axis gimbal system to provide solar pointing during its seven year duration. The focal point insert will be changed to accommodate Brayton, Stirling, and Rankine thermal cycles. The attached radiator system supports radiator technology development experiments. Thermal interface technology experiments are also included in this testbed.



# Thermal Energy Generation & Management Testbed

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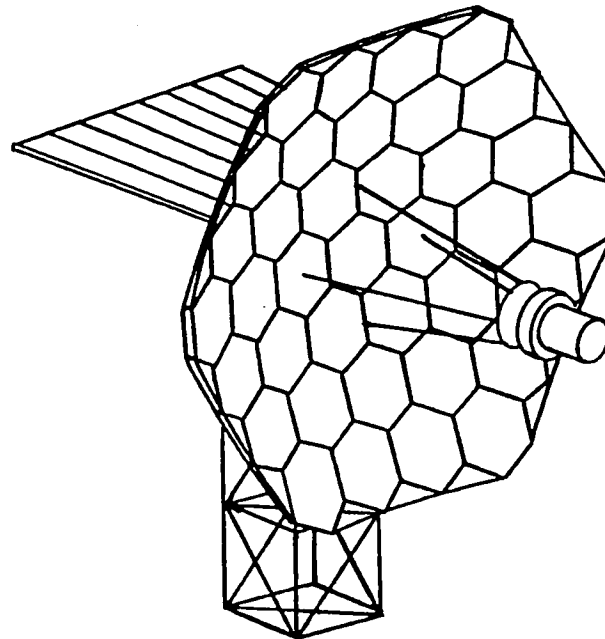
BOEING

TDMX      TITLE

2153 Solar Dynamic Power

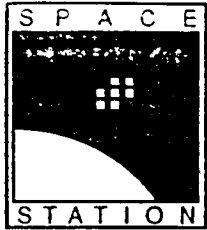
2131 Radiator Technology

2565 Thermal Interface Technology



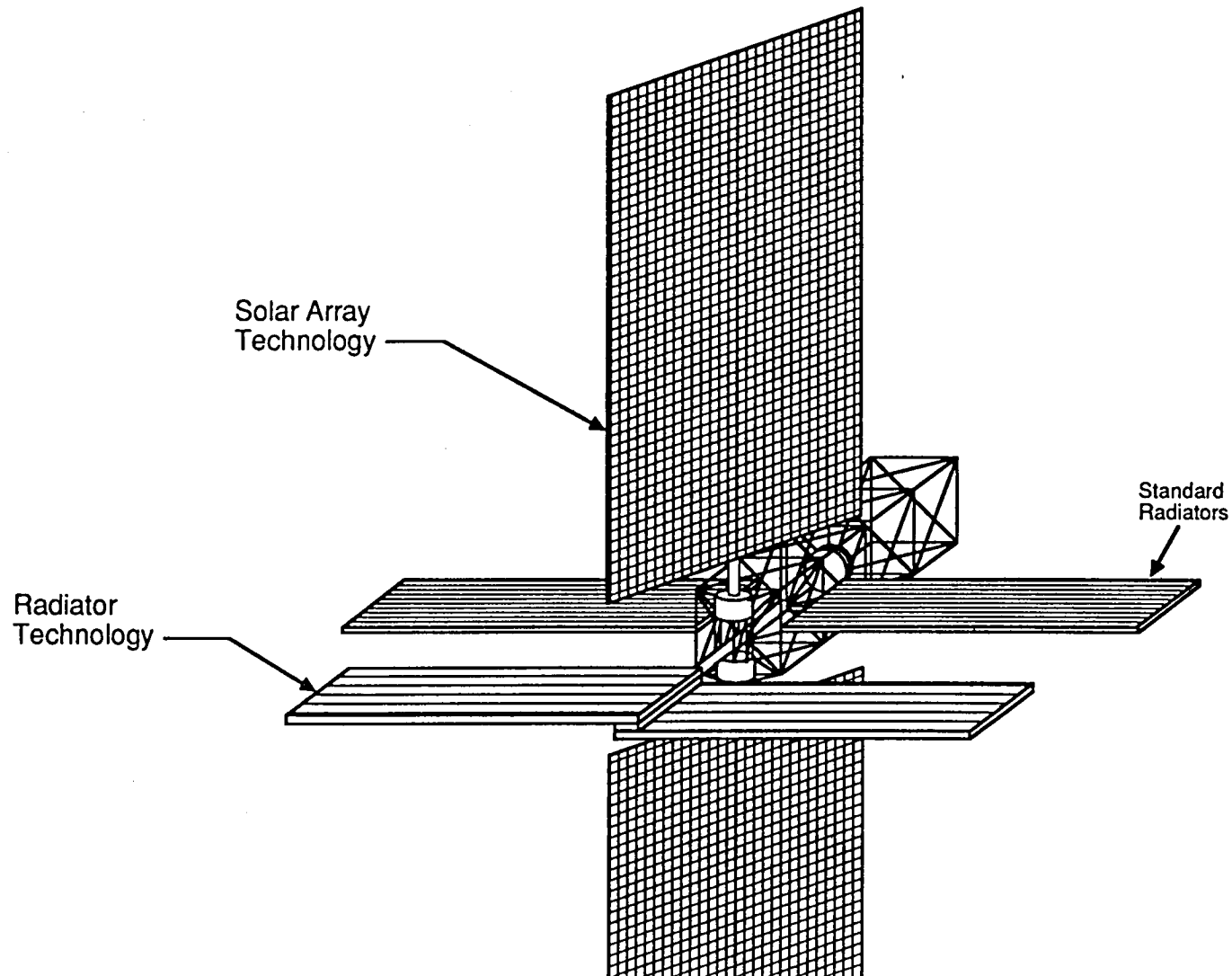
## Photovoltaic Power Generation & Management Testbed

A potential configuration for the Photovoltaic Power Generation & Management Testbed is shown in this figure. It is based on a radiator technology testbed proposed by Wyle Laboratories in a 1987 study for NASA MSFC entitled "Definition of Technology Development Mission for Early Space Station, TDMX 2131 Radiator Technology". Provisions for solar array technology experiments have been added, and a proven radiator design is included to serve as a backup for the experimental radiator concepts.



# Photovoltaic Power Generation & Management Testbed

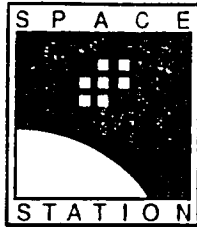
BOEING





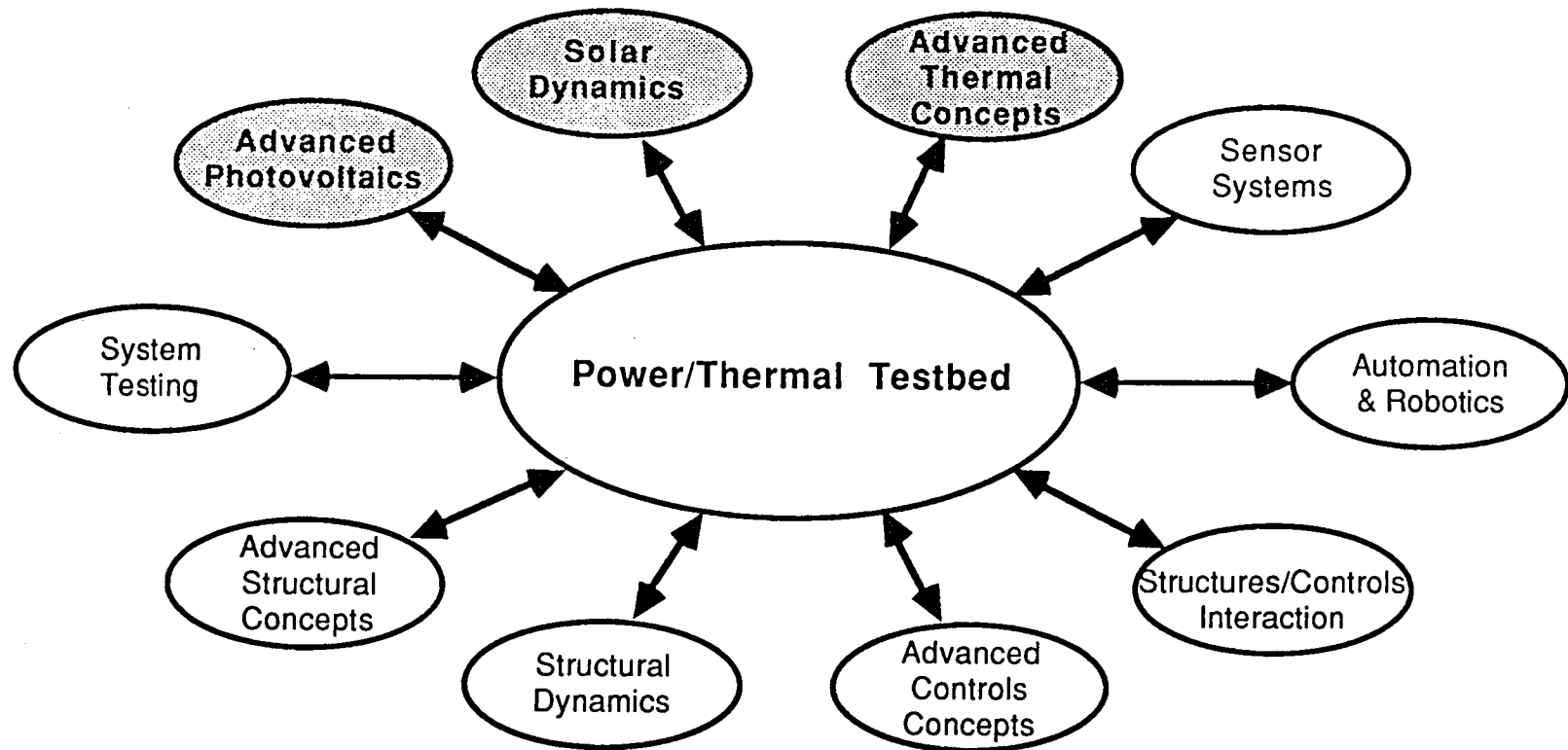
## Technology Areas Supported by the Power/Thermal Testbeds

The primary technology areas served by this testbed, shown in the shaded bubbles, are related to power generation & management and to thermal control. Secondary technology benefits, shown in the unshaded bubbles, will be realized during operation of the testbed.



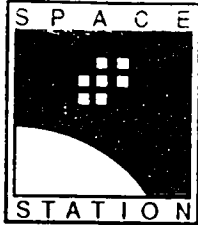
# Technology Areas Supported by the Power/Thermal Testbed

BOEING



## Energy Systems & Thermal Management Individual Facilities

This chart lists the Energy Systems & Thermal Management theme area experiments that do not appear to fit into the proposed testbeds. They will most likely require separate facilities. TDMX 2132 involves exposed fluids that are a potential source of contamination. TDMX 2154 requires a large amount of space station power. The array blanket zero-g fold-up experiment is primarily a structures experiment. The direct solar thermal furnace cannot be combined with the solar dynamic power generation experiment because of the latter's requirement for seven years of continuous operation.



# **Energy Systems & Thermal Management. Individual Facilities**

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*BOEING*

**2132 - Advanced Radiator Technology**

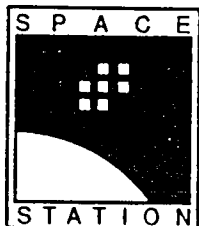
**2154 - Megawatt Power Distribution**

**ABZF- Array Blanket Zero-G Fold-up**

**DSTF - Direct Solar Thermal Furnace**

## General On-Orbit Facilities Requirements Information Systems

The primary locations for experiments in the three categories within the Information Systems theme area are shown in this figure. Many of these experiments are small and can be conducted most efficiently within a pressurized module. Sensor systems and communication systems, however, have applications that will be conducted externally.



# General On-Orbit Facilities Requirements, Information Systems

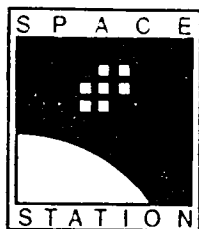
BOEING

Experiment Category	Location			Remote	Comments
	Internal Press.	External/Attached Press.	Unpress.		
Sensor Systems	✓		✓		Sensor technology verification will use existing Space Station or experiment structures. Lab facility is required.
Computer/Data Systems	✓				Computer/data system experiments can be integrated into the Space Station Lab facility.
Communications Systems	✓		✓		Communications system experiments can be integrated into the Structures & Controls antenna experiments.

↑  
Area of interest

## Information Systems Experiments Considered

A list of externally mounted experiments in the Information Systems theme area is shown in this figure. They are a combination of experiments described in the NASA Mission Requirements Data Base (MRDB) and those that were proposed at the In-Space RT&E Workshop.



# Information Systems

## - Experiments Considered -

BOEING

### TDMX

### TITLE

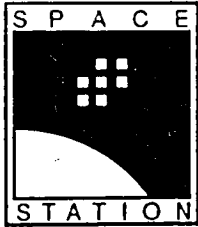
2211	Multi-Function Space Antenna Range Technology
2212	Multi Antenna Beam Patterns
2221	Laser Communications & Tracking Development
2223	Maser Precision Time Generation
2224	Space-Based Optical DSN Terminal
2261	Sensor Systems Technology Experiment
2262	Manned Observations Techniques
2263	CO <sub>2</sub> Doppler LIDAR Wind Sensor
2265	Satellite Doppler Meteorological Radar
2266	Spacecraft Optical Range Determination
2267	Optical Spatial Tracking Spacecraft
- - - -	Space Based Radar
- - - -	High-Voltage Traveling Wave Tube Amplifier
- - - -	Advanced VLBI Technology



Information Systems  
Consolidation Within Theme

The candidate experiments were grouped into four categories: Antenna Technology, Communications, Tracking and Radar, and Phenomenological Experiments.

Some of the antenna technology experiments determine the characteristics of large space antennas and others are demonstrations of the application of antenna technology. Laser and optical communications experiments are proposed for short and long range communications. Optical and radar tracking device experiments and several experiments to measure phenomenological events are also proposed.



# **Information Systems**

## **- Consolidation Within Theme -**

**BOEING**

### **Experiment Groupings:**

- **Antenna Technology**

- 2211 Multi-Function Space Antenna Range Technology
- 2212 Multi Antenna Beam Patterns
- 2261 Sensor Systems Technology Experiments
- - - - Advanced VLBI Technology

- **Communications**

- 2221 Laser Communications & Tracking Development
- 2224 Space-Based Optical DSN Terminal

- **Tracking and Radar**

- 2265 Satellite Doppler Meteorological Radar
- 2266 Spacecraft Optical Range Determination
- 2267 Optical Spatial Tracking Spacecraft
- - - - Space Based Radar

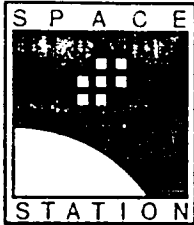
- **Phenomenological Experiments**

- 2223 Maser Precision Time Generation
- 2262 Manned Observations Techniques
- 2263 CO<sub>2</sub> Doppler LIDAR Wind Sensor
- - - - High-Voltage Traveling Wave Tube Amplifier

## Information Systems Consolidation Assessment

Several observations are made after an examination of the consolidation groupings. First, TDMX 2211, 2212 and VLBI experiments were defined by JPL to use the same antenna structure as TDMX 2071, 2411, 2412 and 2413. Therefore, they should be incorporated with the antenna technology testbed experiments. Second, the maintenance and support of sensor system experiments is envisioned to be accomplished within a Sensor Systems Technology Laboratory. Third, most of the other experiments are specialized and have unique sensor and equipment requirements.

The conclusion reached after these observations is that, with the exception of the three antenna experiments, the information systems experiments do not lend themselves to being consolidated into multipurpose testbeds.



# **Information Systems - Consolidation Assessment -**

**BOEING**

## **Observations:**

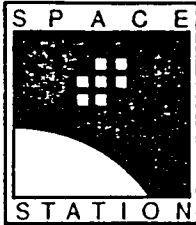
- **TDMX 2211, 2212 and VLBI experiment use the same antenna testbed as 2071, 2411, 2412 & 2413.**
- **A Sensor Systems Technology Laboratory is envisioned to support and maintain sensor systems experiments.**
- **Other experiments have specialized sensors & equipment.**

## **Conclusion:**

- **With the exception of the three antenna experiments, the information systems experiments do not lend themselves to being consolidated.**

## General On-Orbit Facilities Requirements Automation and Robotics

This chart lists the locations for experiments in four categories within the Automation and Robotics theme area. In general, automation and robotics experiments will occur within pressurized modules, attached externally to the space station, and on remote locations, including free-flying robots. This study will address only the externally attached robotic experiments. The Mobile Remote Manipulator System (MRMS) can initially be used as an external robotic testbed.



# General On-Orbit Facilities Requirements, Automation and Robotics

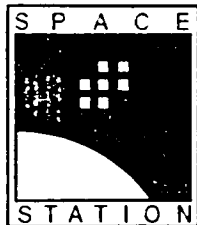
BOEING

Experiment Category	Location				Comments
	Internal Press.	External/Attached Press.	Unpress.	Remote	
Mobility	✓		✓	✓	These comments apply to all topics: Most AI-based autonomous capabilities and robotics could be demonstrated on the ground, however in-space experiments are essential to demonstrate zero-g effects. Internal, external and free-flying robots are envisioned. Internal facilities can be part of the Lab Module. External experiments will probably be conducted as part of other technology demonstrations (construction, servicing, docking, etc.). Initially, the MSC could be used as an external robotic testbed.
Dextrous Manipulation	✓		✓		
Supervise/Autonomous Robotics	✓		✓	✓	
Advanced Concepts	✓		✓	✓	

↑  
Area of interest

## Automation & Robotics Experiments Considered

Experiments listed in the NASA Mission Requirements Data Base (MRDB) and those that were proposed at the In-Space RT&E Workshop in the Automation and Robotics theme area are listed in this figure. The experiments that represent the types of experiments that will be conducted in the near-IOC timeframe are identified with an asterisk. The experiments cover technology topics from the performance of robotic systems to the interaction between man and machine.



## Automation & Robotics - Experiments Considered -

BOEING

### TDMX

### TITLE

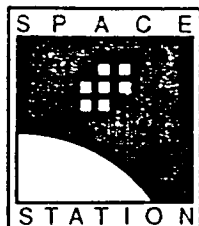
2021	Man/Machine Mix Investigations
2461*	Teleoperated Structure Assembly
2462*	Dextrous Teleoperator Technology
2463	Autonomous Robotic Maintenance Demonstration
2464	Autonomous Servicing Robot
2471	Human/Machine Interface Workload
2472	Advanced Automation Technology
2473	Advanced Robotic Workstation Technology Demonstration
- - - -	Flight vs. Ground Command of Service Robot
- - - -	Astrometric Telescope Facility - Autonomous Operation
- - - -	Dynamics of Retargeting and Maneuvering of LSS
- - - -	Space Power Systems: Automation & Robotics Space Exp.
- - - -	Berthing/Docking Mechanisms and Control Experiment
- - - -	Space Spider Crane

\* IOC Timeframe



## Automation & Robotics Consolidation Within Theme

Four groupings of experiments become evident after a review of the list of externally mounted robotic experiment candidates. The first group contains those experiments that use automation and robotics to assemble or manipulate structures. The second group is a set of experiments that demonstrate the technologies related to servicing and maintenance. The technologies that relate to the manner in which humans interact with robots are demonstrated by the third grouping. The fourth grouping contains experiments that demonstrate operations using automation and robotics.



## **Automation & Robotics - Consolidation Within Theme -**

BOEING

### **Experiment Groupings:**

- **Structural Assembly/Manipulation**

- 2461 Teleoperated Structural Assembly
- 2462 Dextrous Teleoperator Technology
- - - Dynamics of Retargeting and Maneuvering of LSS
- - - Space Spider Crane

- **Servicing**

- 2463 Autonomous Robotic Maintenance Demonstration
- 2464 Autonomous Servicing Robot
- 2472 Advanced Automation Technology

- **Man/Machine Interaction**

- 2021 Man/Machine Mix Investigations
- 2471 Human/Machine Interface Workload
- 2473 Advanced Robotic Workstation Technology Demonstration

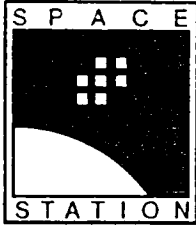
- **Operations**

- - - Flight vs Ground Command of Service Robot
- - - Astrometric Telescope Facility - Autonomous Operation
- - - Space Power Systems: Automation & Robotics Space Exp.
- - - Berthing/Docking Mechanisms and Control Experiment

## Automation & Robotics Consolidation Assessment

Several observations are presented here after a review of the experiments within the Automation and Robotics theme area. First, automation and robotics experiments involve the manipulation of structural elements or other objects. Second, servicing and maintenance of satellite systems will occur within the satellite servicing hangar. And, third, human involvement will accompany all automation and robotic experiments until enough confidence is achieved that unattended operation of robots is reliable and safe.

It is concluded that, since most automation and robotic operations serve specific operations, the technology development experiments should be incorporated into the theme areas that the A&R experiments serve. For example, the robotic assembly of space structures experiments should be incorporated with the Large Structures Testbed.



# **Automation & Robotics - Consolidation Assessment -**

**BOEING**

## **Observations:**

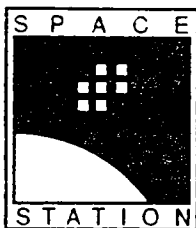
- **Structural elements are required for telerobotics experiments.**
- **Robotic servicing & maintenance experiments will occur within the satellite servicing hangar.**
- **Man/machine interaction and operations experiments will be a part of all robotic and telerobotic experiments.**

## **Conclusions:**

- **Teleoperator experiments for structural assembly should be integrated with a large space structures testbed.**
- **The A&R operations experiments should be integrated with the technology area served.**

## Automation & Robotics Testbed Experiments

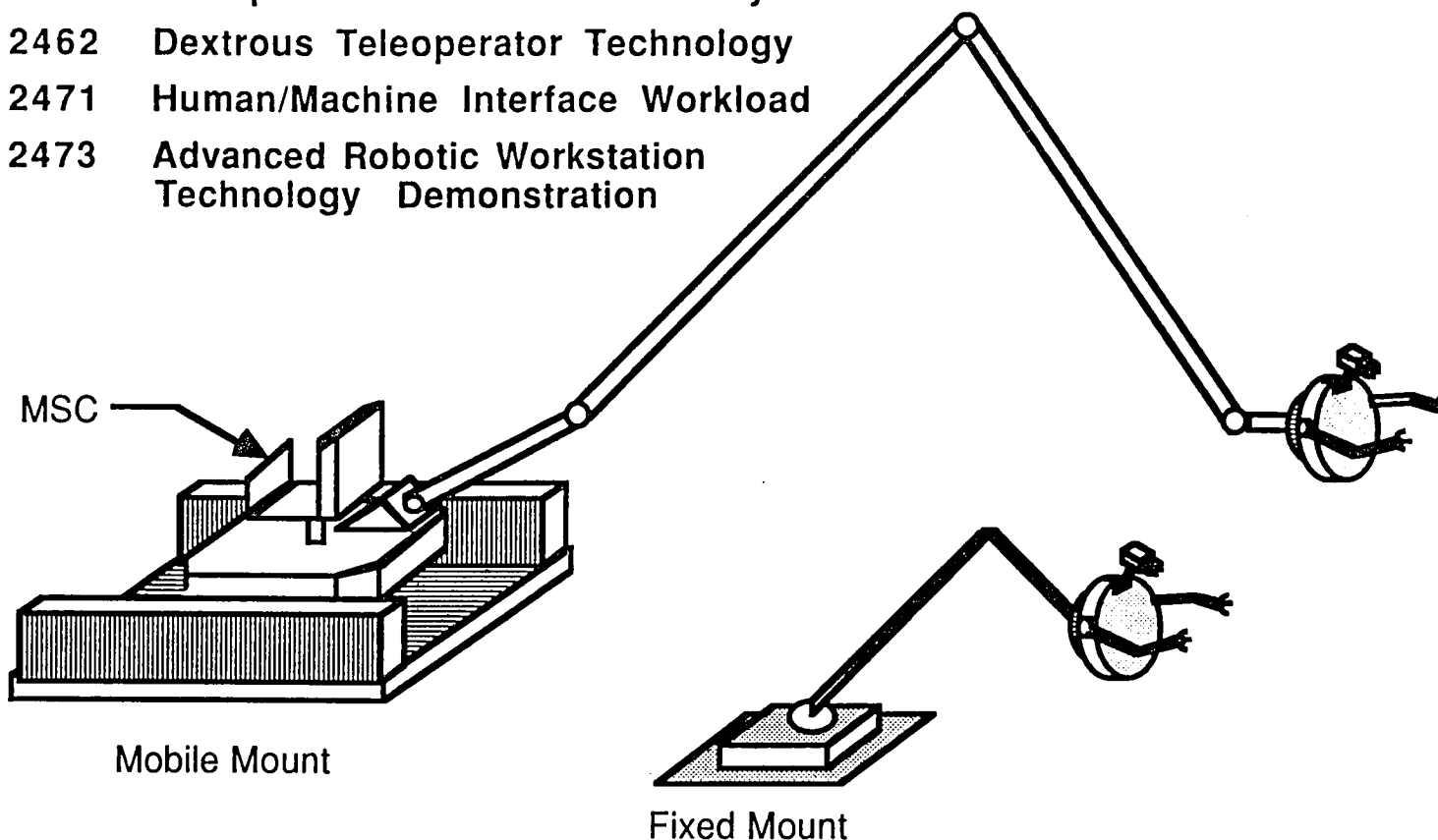
This figure depicts possible automation and robotics testbeds for the space station. The technology development experiments listed include those that demonstrate automation and robotic operation and performance as well as those that demonstrate human interaction with robotics. As indicated in the figure, early robotic experiments can be conducted using the Mobile Service Center (MSC) on the space station as the device to position the robot. Then, as the technology progresses, a fixed mount system can be included. The fixed mount arm is a relatively simple controllable arm with three articulating joints. It could be made less complicated and, therefore, less expensive than the MSC arm.



# Automation & Robotics Testbed Experiments

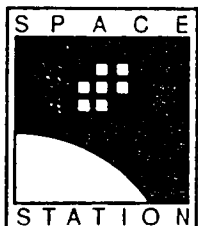
BOEING

<u>TDMX</u>	<u>TITLE</u>
2021	Man/Machine Mix Investigations
2461	Teleoperated Structure Assembly
2462	Dextrous Teleoperator Technology
2471	Human/Machine Interface Workload
2473	Advanced Robotic Workstation Technology Demonstration



## General On-Orbit Facilities Requirements In-Space Operations

Listed in this figure are the experiment categories in the In-Space Operations theme area and their desired locations. The primary location for many of the experiments is inside pressurized modules, with some needing both internal and external locations. For example, the scope of maintenance and repair and system testing will determine whether they will be internal or external experiments. Both locations will be required to demonstrate these technologies for space station. Propulsion technology development experiments will most likely require a location remote from the space station because of the disturbances generated and the potential for contamination. The location for material processing experiments is primarily within a pressurized module, depending on the size and scale of the processes involved. External locations may be required if fabrication technology is included in this category.



# General On-Orbit Facilities Requirements, In-Space Operations

BOEING

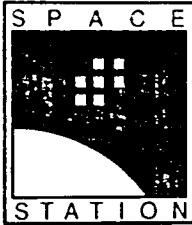
Experiment Category	Location				Comments
	Internal Press.	External/Attached Press.	Unpress.	Remote	
Advanced Life Support Systems	✓				Needs laboratory facility. Leads to CELSS
Biomedical Research	✓				Needs laboratory facility. (LSRF)
Tethers			✓		Needs external research facility.
Maintenance and Repair	✓		✓		External & internal facility required.
Orbital Transfer Vehicles			✓		Needs large external servicing facility. May combine with fluid research & propulsion
System Testing	✓		✓		Needs internal control station. Performs tests on internal & external systems.
Propulsion				✓	Co-orbiting facility may be required due to disturbances and contamination produced.
Material Processing	✓		✓		Lab required. May need external facility if fabrication technology is included.

↑  
Area of interest



## In-Space Operations Experiments Considered

This figure lists the proposed externally attached experiments in the In-Space Operations theme area described in the NASA Mission Requirements Data Base (MRDB) and at the In-Space RT&E Workshop. Most of the experiments deal with tether technology and servicing and maintenance of various systems. The technology development experiments judged by NASA to be representative of near IOC experiments are marked with an asterisk.



# In-Space Operations

## - Experiments Considered -

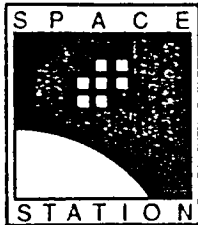
BOEING

<u>TDMX</u>	<u>TITLE</u>
2541	Tethered Electrodynamic Power generation
2542	Tethered Constellation
2543	Tethered Transportation
2544	Tethered Fluid Storage/Transfer
2561*	Satellite Servicing and Refurbishment
2562*	Satellite Maintenance and Repair
2563	Materials Resupply
2564	Coatings Maintenance Technology
2571*	OTV/Payload Interfacing and Transfer
2573*	OTV Docking and Berthing
2574*	OTV Maintenance Technology
- - - -	STS Deorbit/OTV Boost From S.S. Using a Tether
- - - -	Systems Operational Maintenance Technology
- - - -	Manned System Experiments
- - - -	Automatic Satellite Checkout Equipment
- - - -	Escape and Recovery Experiments

\* IOC Timeframe

## In-Space Operations Consolidation Within Theme

The 16 experiments in the In-Space Operations theme area fall into four distinct categories: tethers, satellite servicing, OTV servicing and manned operations. Some of the technologies demonstrated in the satellite servicing category also apply to the servicing and maintenance of space station systems.



# **In-Space Operations**

## **- Consolidation Within Theme -**

**BOEING**

### **Experiment Groupings:**

- **Tethers**

- 2541 Tethered Electrodynamic Power Generation
- 2542 Tethered Constellation
- 2543 Tethered Transportation
- 2544 Tethered Fluid Storage/Transfer
- - - - STS Deorbit/OTV Boost From S.S. Using a Tether

- **Satellite Servicing**

- 2561 Satellite Servicing and Refurbishment
- 2562 Satellite Maintenance and Repair
- 2563 Materials Resupply
- 2564 Coatings Maintenance Technology
- - - - Systems Operational Maintenance Technology
- - - - Automatic Satellite Checkout Equipment

- **OTV Servicing**

- 2571 OTV/Payload Interfacing and Transfer
- 2573 OTV Docking and Berthing
- 2574 OTV Maintenance Technology

- **Manned Operations**

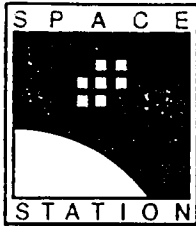
- - - - Manned System Experiments
- - - - Escape and Recovery Experiments

## In-Space Operations Consolidation Assessment

A review of the experiments in the In-Space Operations theme area leads to the observations and conclusions shown in this figure.

A dedicated facility will be required to conduct tether experiments, and satellite servicing experiments will be conducted within the satellite servicing facility. OTV servicing will also require a specialized facility that may or may not be attached to the space station.

It is, therefore, concluded that separate testbed facilities are required for tethers, satellite servicing and OTV servicing. Manned system operations will be required in varying degrees by all of the technology development experiments and will be integrated with them. Therefore, no dedicated testbed is recommended for manned system operations.



# **In-Space Operations**

## **- Consolidation Assessment -**

*BOEING*

### **Observations:**

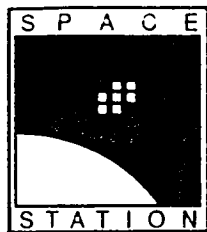
- **Tether experiments will be accommodated by a dedicated facility.**
- **Satellite servicing experiments will be conducted within the Satellite servicing hangar.**
- **OTV servicing will require a specialized facility, possibly remote from the Space Station**

### **Conclusions:**

- **Separate testbed facilities are required for tethers, satellite servicing and OTV servicing.**
- **Manned system operations are an integral part of all technology development experiments.**

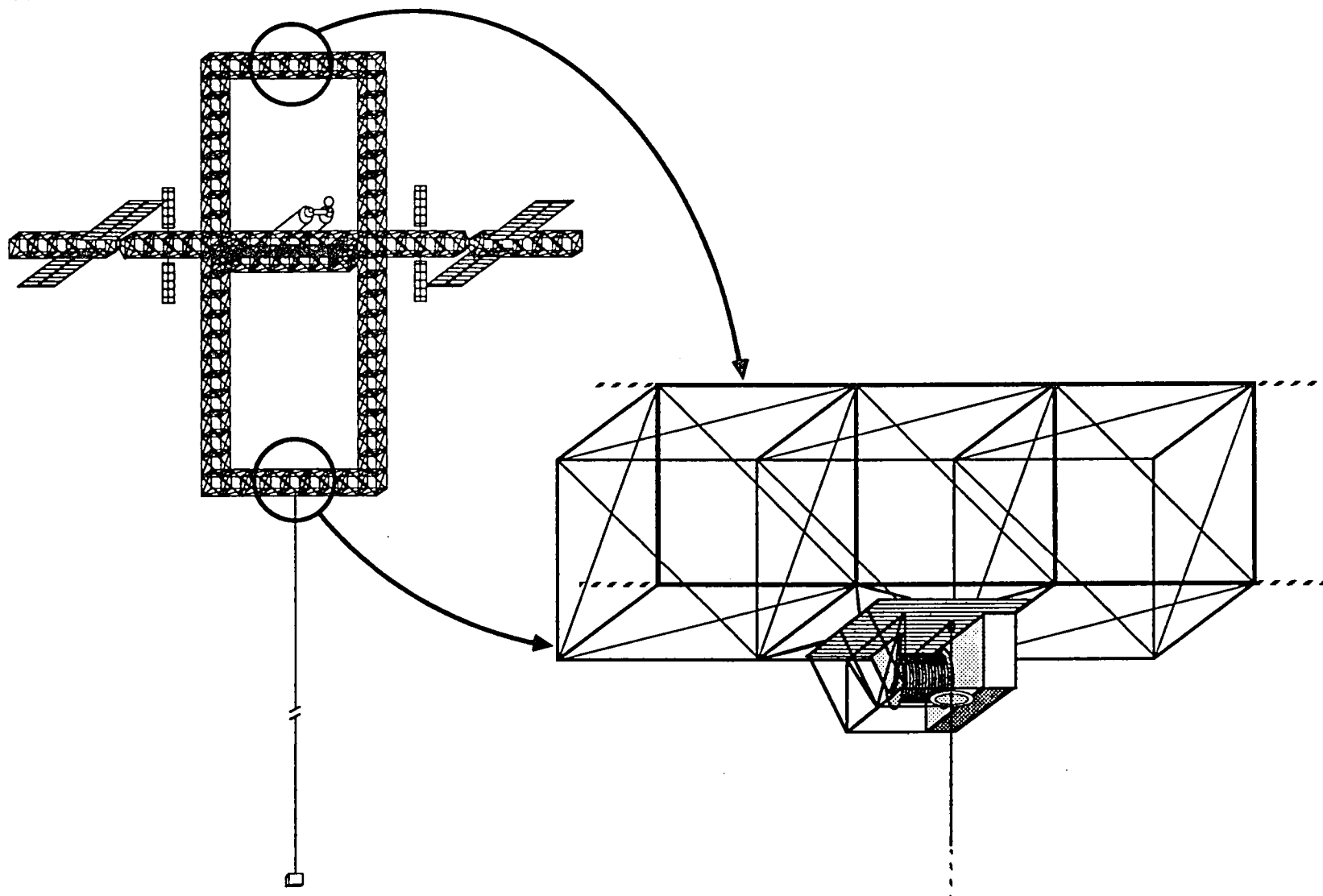
## Tether Testbed Facility

Since satellite servicing experiments will be conducted within the space station satellite servicing facility, and the timing and location of an OTV servicing facility is nebulous, only a tether technology testbed facility is identified in this study. This figure shows a tether technology testbed configuration that can be located either on the lower or upper space station boom.



# Tether Testbed Facility

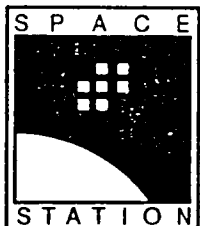
BOEING





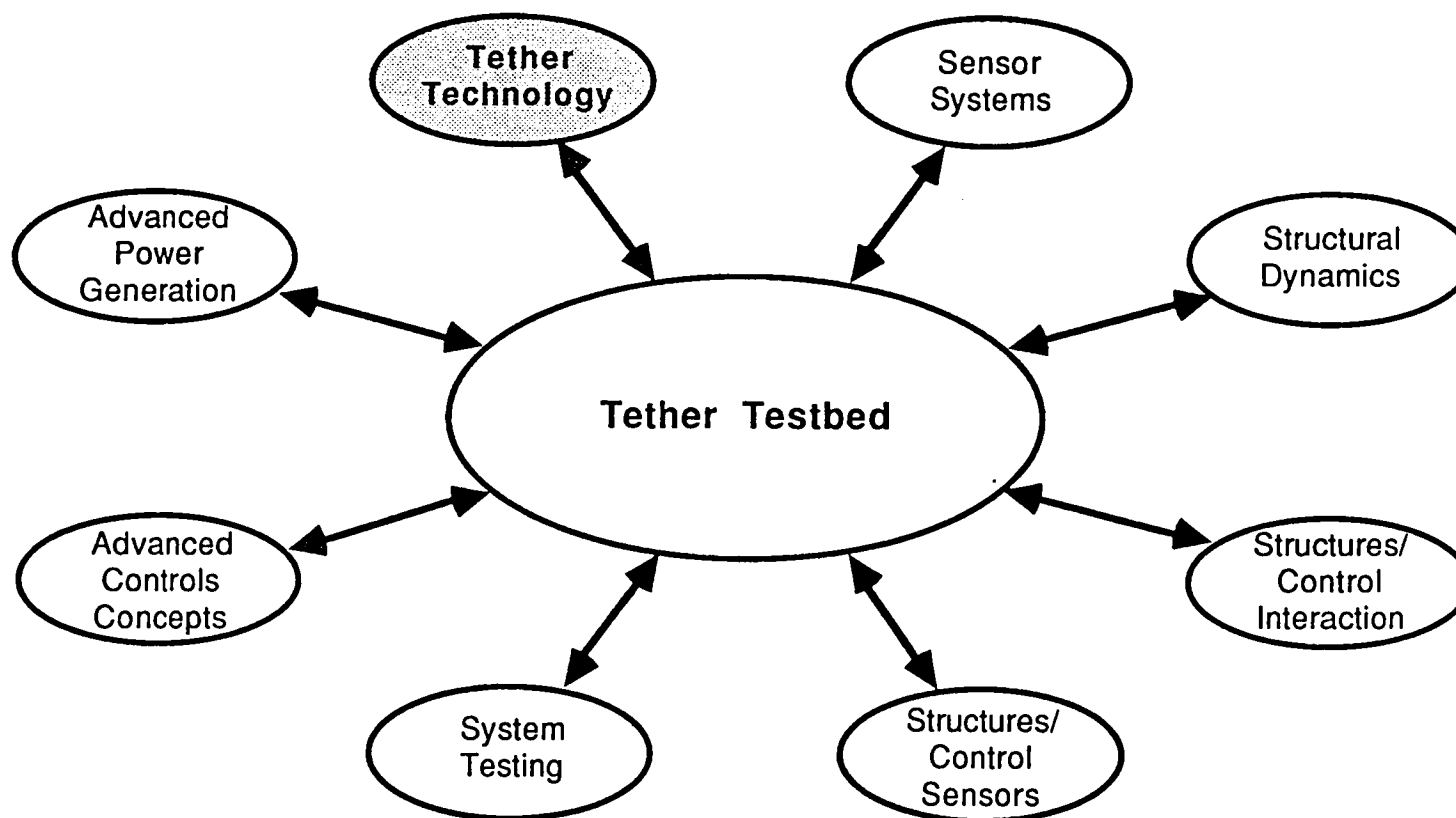
## Technology Areas Supported by the Tether Testbed

The primary benefit of a tether testbed is the development and demonstration of tether technology. Secondary technology areas, shown in the figure in unshaded bubbles, will also be advanced by this testbed and the application of tether technology.



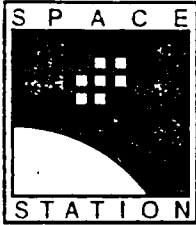
# Technology Areas Supported by the Tether Testbed

BOEING



Recommended Laboratory Module  
(Space Station growth)

After reviewing all of the TDMX experiments and those that were proposed at the NASA In-Space Research, Technology and Engineering (RT&E) Workshop, along with the recommendations from the seven workshop panels, it became apparent that all of the seven technology theme areas would benefit from, if not require, a portion of a laboratory module to accomplish their goals. The tasks in each theme area that could be accomplished in a RT&E Laboratory are shown in this figure. It is, therefore, recommended that a RT&E Laboratory module be included in the plans for space station growth.



## Recommended Laboratory Module (Space Station growth)

BOEING

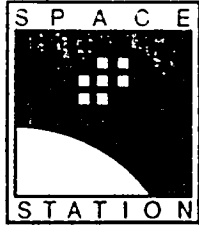
### RT&E Laboratory

- **Structural concepts**
  - Materials research
  - Advanced structural concepts evaluation & test
  - Structural sensors
  - Fabrication technology
  - On-orbit structural repairs
- **Fluid management**
  - Fluid sensors & measurement
  - Fluid behavior
- **Space environmental effects**
  - Materials evaluation
  - Electronics testing
  - Environmental research
- **Energy Systems & Thermal Mgmt.**
  - Component & sample evaluation
- **Information systems**
  - Sensor systems development & maintenance
  - Algorithm development and confirmation
  - Computer/data systems
- **Automation & robotics**
  - Robotics research & maintenance
- **In-space operations**
  - System test control station

## Summary

In summary, a review of the NASA Mission Requirements Data Base (MRDB) and the results of the In-Space Research, Technology and Engineering (RT&E) Workshop has led to a number of testbeds that will promote an accelerated technology return by combining experiments, and by providing test articles for use by smaller experiments that might otherwise be difficult to justify. They also provide for the consolidation of experiments with similar objectives and goals. Economy of space station resources is also accomplished by providing a common location on the space station for similar experiments, and by careful planning and time-phasing. By combining smaller experiments with larger, higher priority experiments, the priority of the smaller experiments is enhanced, and the larger experiment benefits from the technology provided by the smaller experiment. The testbeds also promote a continuous RT&E program by providing facilities that can grow and evolve as new technology advancements occur.

A dedicated RT&E laboratory module on the growth space station will provide a test and maintenance lab in space. It will provide a low-g environment for experimentation that is separated from the habitation modules and labs used for biological research. Human interaction with RT&E experiments and tests will enhance the technology return, and a facility for maintenance and repair of components and sensors is provided. The on-orbit RT&E laboratory will also reduce the amount of material that must be returned to Earth. Minor repairs can be accomplished in the lab, modifications to experimental hardware can be made, and experiment samples can be tested, evaluated and returned to the experiment. Sample materials that are to be destroyed can be jettisoned to reenter the Earth's atmosphere and burn up.



# Summary

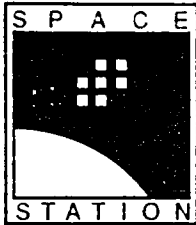
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- **Technology testbeds will promote:**
  - Accelerated technology return
  - Consolidation of facilities
  - Economy of space station resources
  - Enhancement of priorities
  - Continuous RT&E program
- **Dedicated lab module supports RT&E**
  - Provides low g environment
  - Allows interaction with experiments
  - Provides facility for maintenance/repair
  - Reduces return mass

### Summary of Recommended Testbeds (External, Attached)

Eight testbeds are recommended for technology development experiments that are attached externally to the space station. A large space structures construction and servicing facility will serve as a space structures testbed. During its construction, it will demonstrate some of the technologies involved in the Space Structures (Dynamics & Control) theme area. After it is completed, it will serve as permanent space station facility that can be used as a mounting location and a source of space station utilities for five other testbeds: Automation & Robotics, Antenna Technology, Large Precision Segmented Structures, Fluid Management, and Photovoltaic Power Generation and Management. Separate locations for Thermal Energy Generation & Management and for Tether Technology testbeds are recommended. Each of the proposed testbeds will be summarized on subsequent charts.

A pressurized RT&E Laboratory module is also recommended that will permit human interaction with many experiments, will allow more efficient use of laboratory and data handling equipment, will support real-time evaluation of test specimens, and will provide a facility for maintenance and repair.



# **Summary of Recommended Testbeds (External, Attached)**

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## **Testbeds**

- **Large Structures Construction & Servicing**
  - **Automation & Robotics**
  - **Antenna Technology**
  - **Large Precision Segmented Structures**
  - **Fluid Management**
  - **Photovoltaic Power Generation and Management**
- **Thermal Energy Generation and Management**
- **Tether Technology**

## **Pressurized Module**

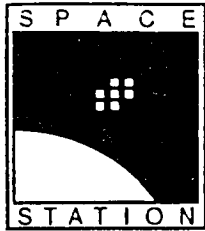
- **RT&E Laboratory**



## Automation & Robotics Testbed on the Large Structures Facility

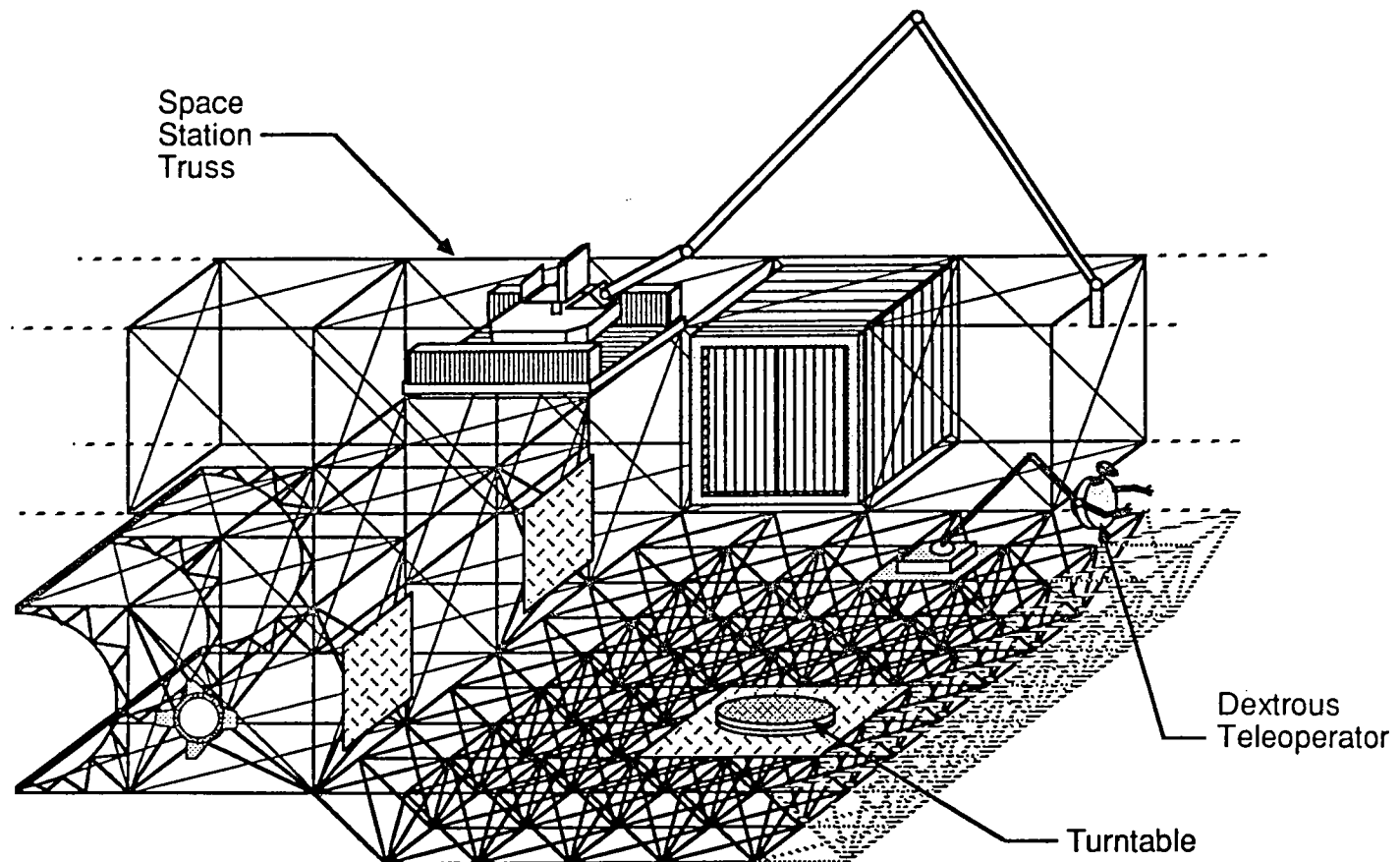
The Large Structures Construction and Servicing Facility is shown with the Automation and Robotics Testbed mounted to it. A large space structures experiment in itself, the Large Structures Facility demonstrates truss structure construction, the determination of the dynamic characteristics of a joint dominated structure, and other technology topics. It provides a large planar area for the accommodation of other experiments and testbeds. It includes an enclosed storage hangar, a turntable, platforms for smaller experiments or equipment, a surrogate payload bay, and a berthing port. Further study is necessary to determine its size, location and accommodations to be provided.

The Automation & Robotics Testbed, shown mounted to a fixed base, could be initially attached to the Manned Service Center (MSC) where it could be used to construct the Large Structures Construction and Servicing Facility. After the facility is operational, the A&R testbed can be used to demonstrate robotic construction, servicing and repair of other experiments.



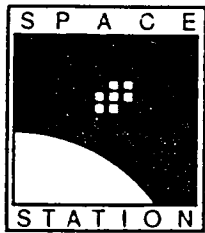
# Automation & Robotics Testbed on the Large Structures Facility

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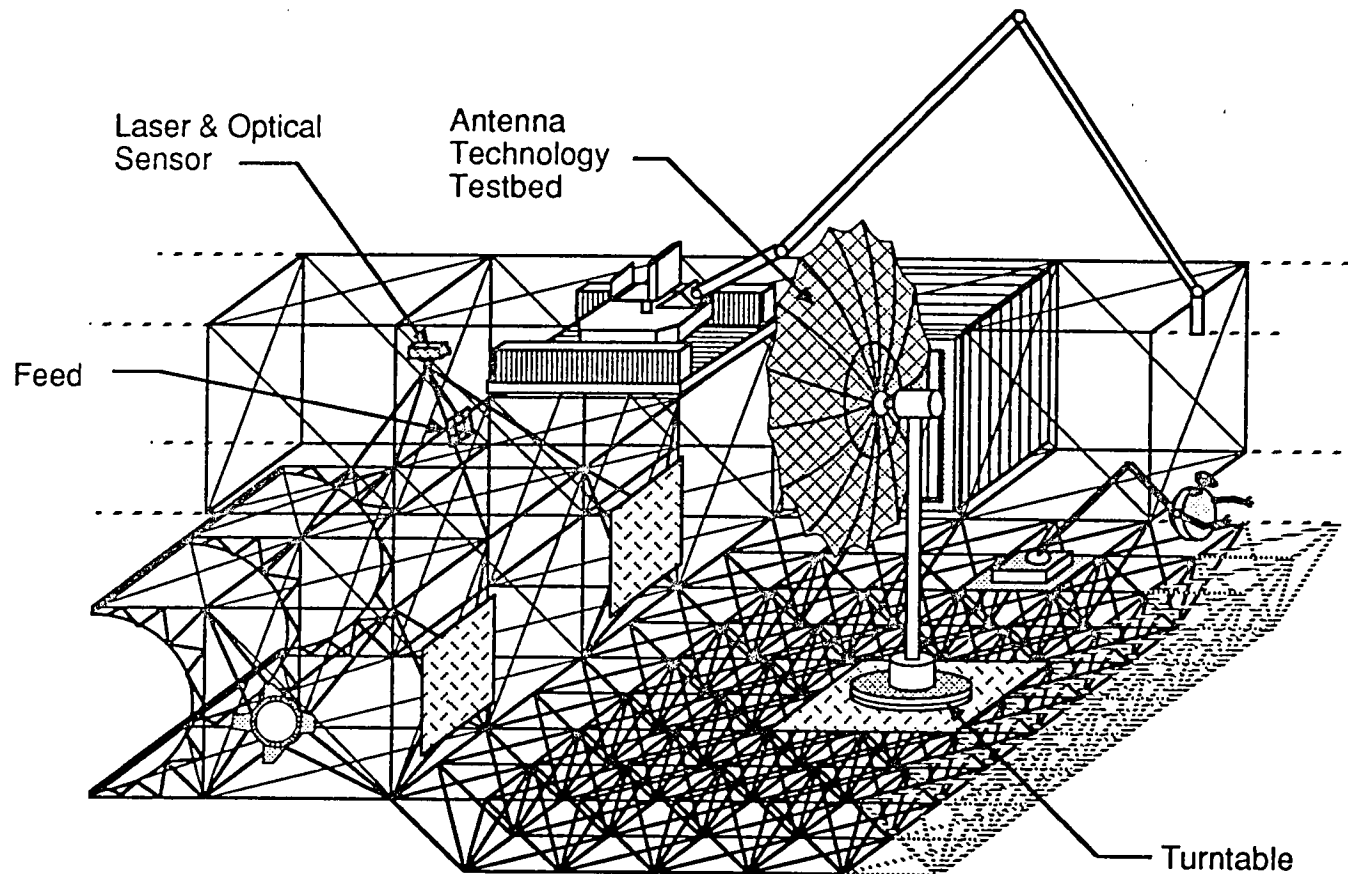
## Antenna Technology Testbed on the Large Structures Facility

The Antenna Technology Testbed is shown attached to the turntable which will allow it to be rotated and aimed at various targets. Surface contour measurement systems and feed arrays required by some of the experiments are shown mounted to the space station truss extension. Near field antenna patterns can be measured in the configuration shown, while far field measurements can be accomplished by rotating the antenna to face away from the space station, using the OMV to perform the measurements.



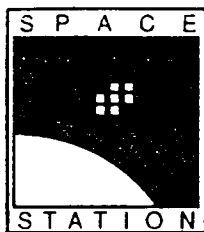
# Antenna Technology Testbed on the Large Structures Facility

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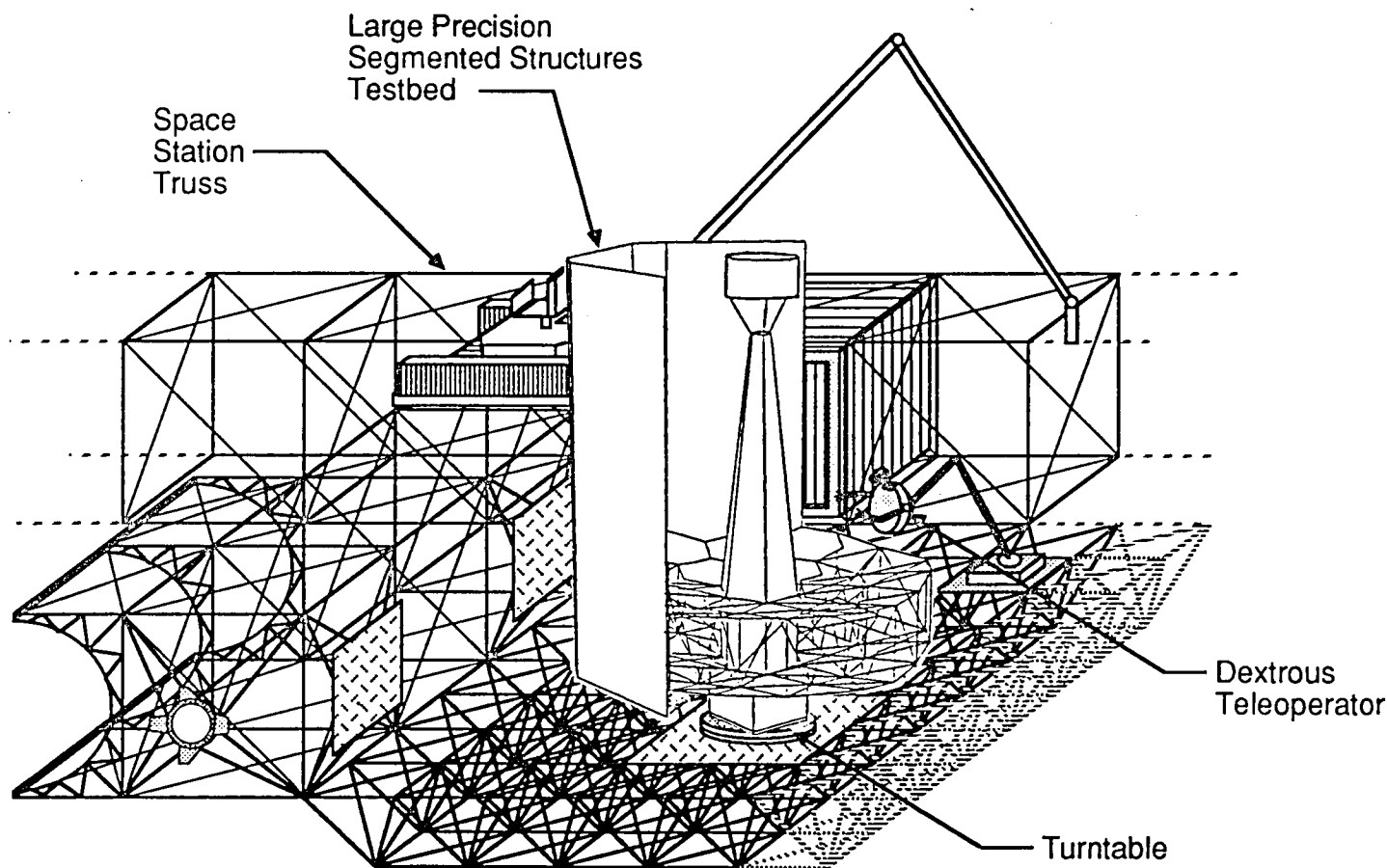
## Large Precision Segmented Structures Testbed on the Large Structures Facility

The Precision Segmented Structures Testbed is shown under construction while mounted to the turntable on the Large Structures Facility. The turntable allows the testbed to be rotated and indexed to allow the dextrous teleoperator (and/or EVA astronauts) to accomplish its construction. Following construction, structural measurements, optical alignment and system tests, it will be moved to the Payload Pointing System (PPS) for conducting pointing and astronomical measurements.



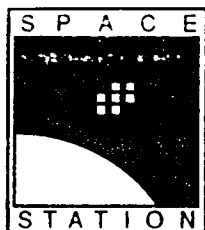
# Large Precision Segmented Structures Testbed on the Large Structures Facility

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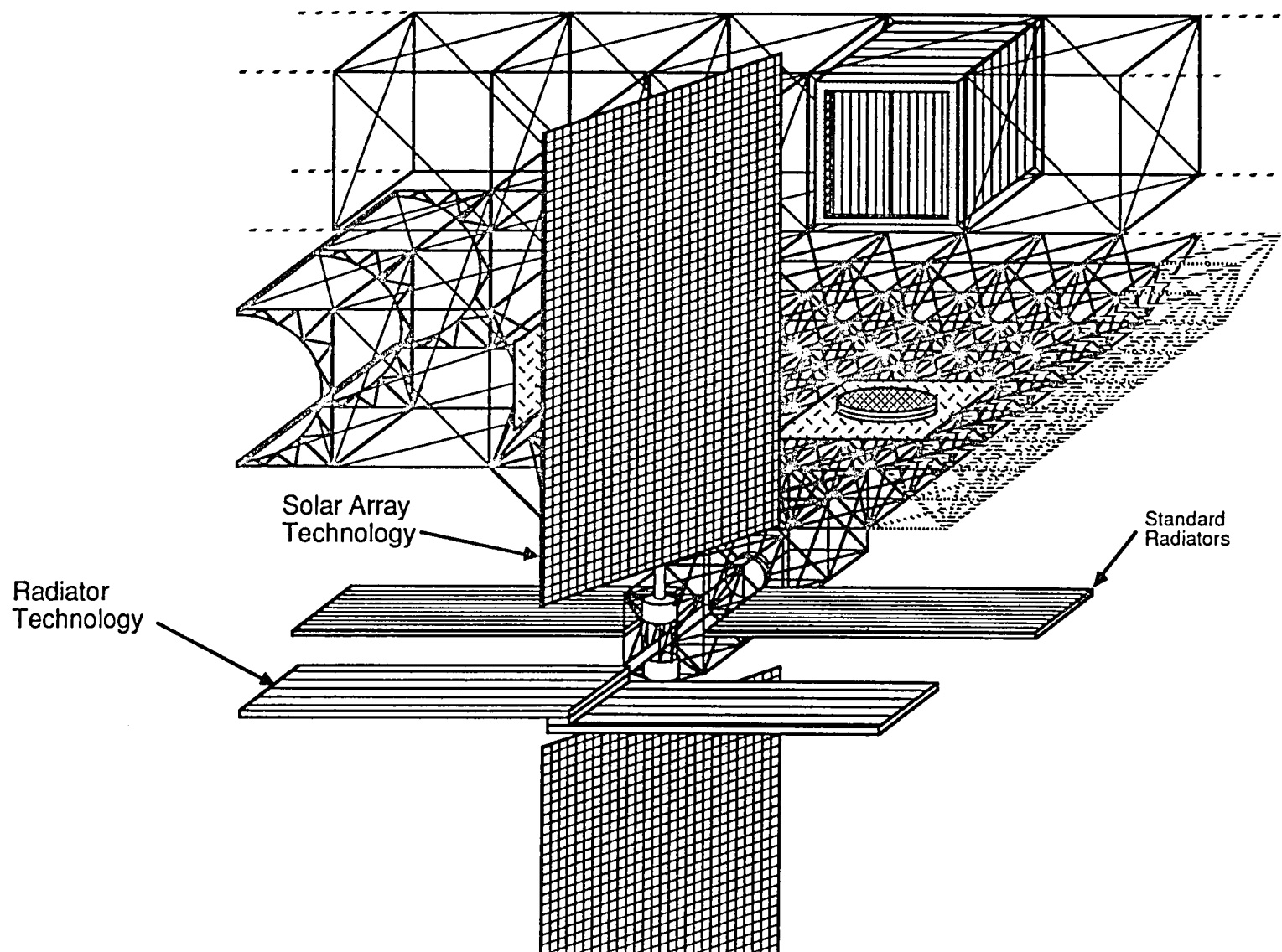
## Photovoltaic Power Generation & Management Testbed on the Large Structures Facility

The Photovoltaic Power Generation & Management Testbed is shown attached to the "bottom" surface of the Large Structures Facility. The box truss beam includes a single axis gimbal to orient the experimental and "standard" radiators to be edge-on to the sun. The solar arrays are also gimballed to orient them toward the sun. Both the experimental solar arrays and radiators are replaceable to accommodate different concepts.



# Photovoltaic Power Generation & Mgmt. Testbed on the Large Structures Facility

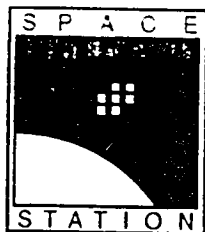
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## Fluid Management Testbed on the Large Structures Facility

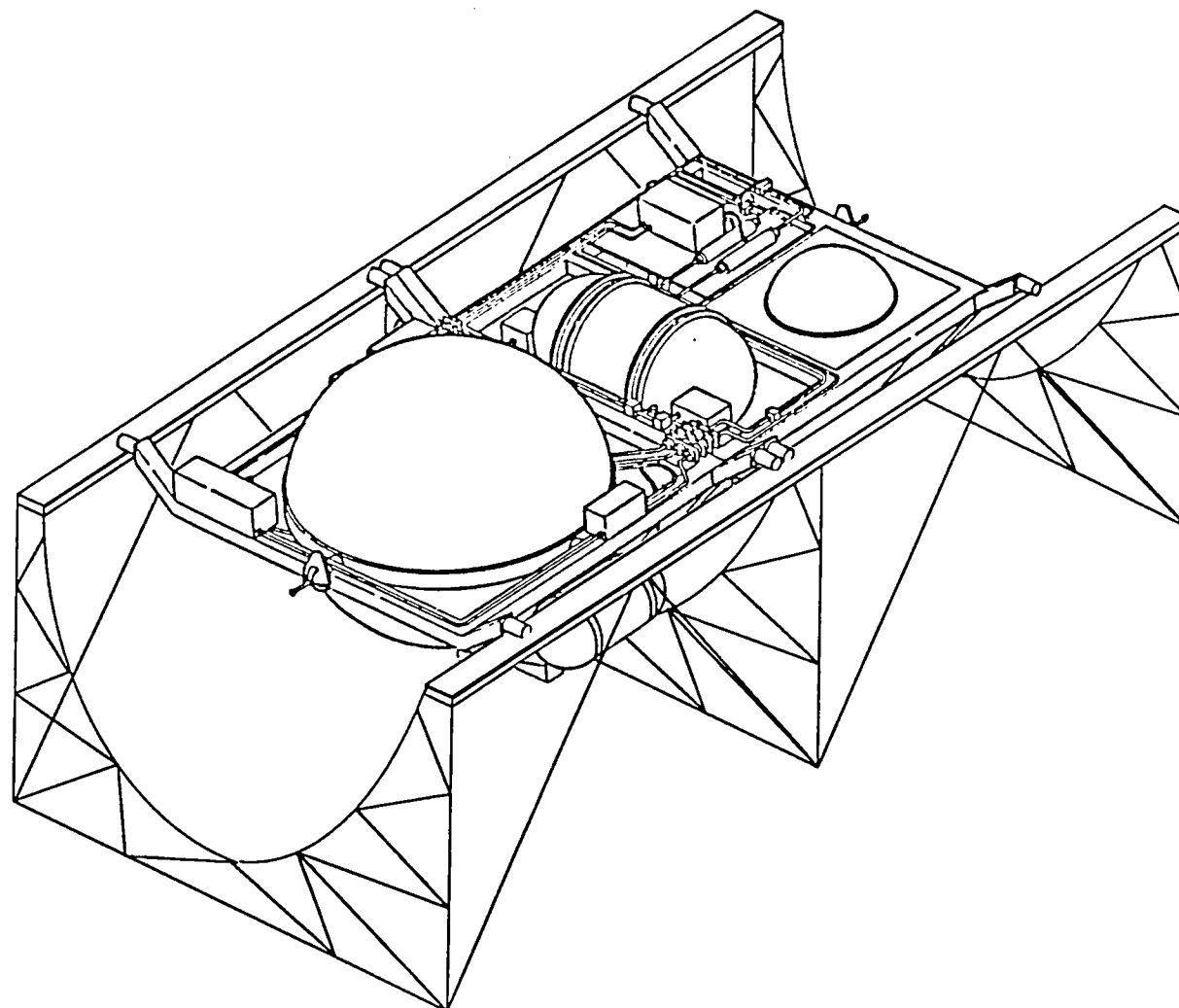
A candidate configuration for the Fluid Management Testbed is shown in this drawing, attached to the Large Structures Facility. It was configured for delivery by the space shuttle and, therefore, could be attached to the space station using a surrogate payload bay mounting system. Mounting provisions, however, will need to be modified to accommodate an alternate delivery system if the shuttle restrictions on cryos continues. More than one testbed may be required to accommodate the thermal and physical characteristics of different cryogenic fluids. An enclosure to protect the testbed from debris and micrometeorites and to contain any unforeseeable leakage may be required if the testbed itself is not designed to provide protection and containment.



# Fluid Management Testbed on the Large Structures Facility

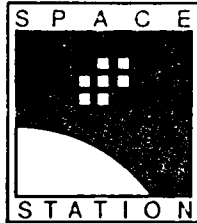
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Surrogate  
Payload Bay



## Experiments Supported by the Large Structures Facility

This figure is a composite list of all technology development experiments described in the NASA Mission Requirements Data Base (MRDB) and those proposed at the NASA In-Space Research, Technology and Engineering (RT&E) Workshop that can be conducted on the proposed Large Structures Facility. It includes those experiments satisfied during the construction of the facility, the experiments accommodated by testbeds mounted to it, and individual experiments that can be conducted on it. The Large Structures Facility represents a major consolidation of facilities, resources and equipment for the advancement of technology in all seven theme areas.



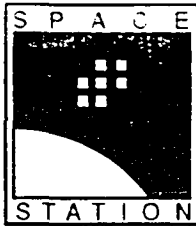
# Experiments Supported by the Large Structures Facility

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- Large Space Structures Technology
  - 2061 Large Space Structures
  - 2062 Space Station Modifications
  - 2072 Spacecraft Strain & Acoustic Sens.
  - - - - - Fiber Optic Sensors in Space Applic.
  - - - - - Struct. Concepts Research Facil.
- Antenna Technology Testbed
  - 2071 Flight Dynamics Identification
  - 2211 Multi-Function Space Antenna Range Technology
  - 2212 Multi Antenna Beam Patterns
  - 2411 Advanced Adaptive Control
  - 2412 Distributed Control Experiment
  - 2413 Dynamic Disturbance Experiment
  - - - - - Large Space Antenna (Reflectors)
  - - - - - Advanced Orbiting VLBI Technology on the Space Station
- Large Precision Segmented Struct. Testbed
  - 2421 Active Optic Technology
  - - - - - TDM for LDR
  - - - - - Precision Optical System Assembly
- Automation & Robotics Testbed
  - 2021 Man/Machine Mix Investigations
  - 2161 Teleoperated Structure Assembly
  - 2462 Dextrous Teleoperator Technology
  - 2471 Human/Machine Interface Workload
  - 2473 Advanced Robotic Workstation
- Photovoltaic Power Gen. & Mgmt. Testbed
  - 2151 Solar Array/Energy Storage Tech.
  - 2152 Large Space Power Systems Tech.
  - 2511 Space Power System Environ. Interf.
  - ENVI Environmental Interaction Experiment
  - 2131 Radiator Technology
  - 2565 Thermal Interface Technology
- Fluid Management Testbed
  - 2311 Long-Term Cryogenic Fluid Storage
  - 2572 Cryo Propel. Transfer/Storage/Reliq.
  - - - - - Helium Transfer in Space
  - - - - - Ultrasonic Fluid Measurement
- Individual Experiments
  - 2064 Adv. Antenna Assembly/Performance
  - 2065 Ion Beam Cold Welding
  - 2066 Inflatable/Rigidizable Struct. Element
  - 2261 Sensor Systems Technology Exp.
  - 2422 Thermal Shape Control
  - 2564 Coatings Maintenance Technology
  - - - - - Berthing & Docking Sensor
  - - - - - In-Space Actively Controlled Structure
  - - - - - Environ. Influence on Struct. Dynam.
  - - - - - 40-105 GHz Propagation Experiment
  - - - - - Solar Array Blanket Zero-G Foldup Exp.
  - - - - - Space Based Radar (SBR)
  - - - - - Space Spider Crane

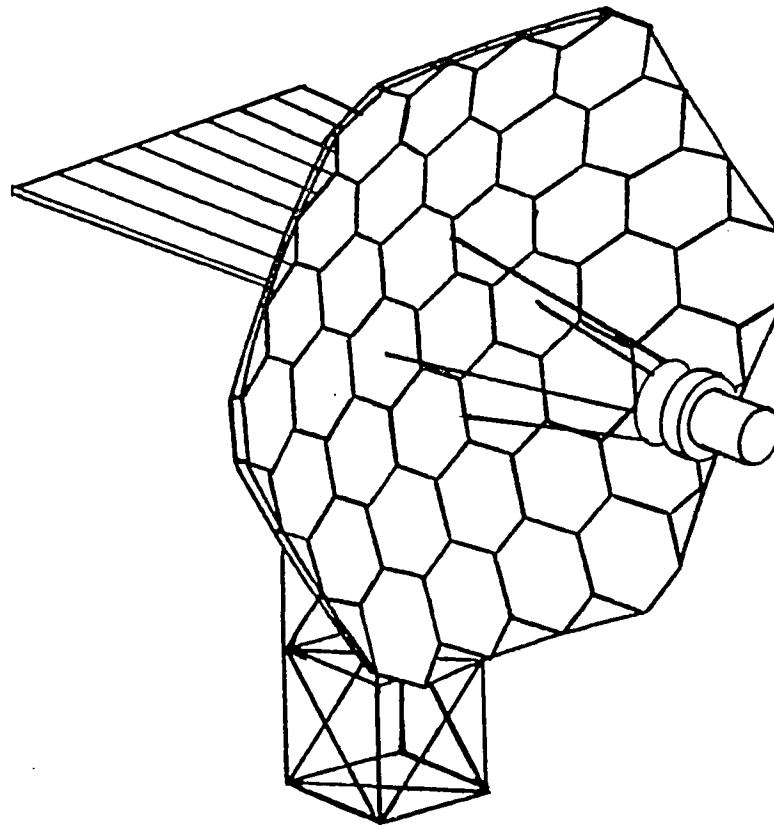
## Thermal Energy Generation & Management Testbed

Because of its pointing requirements and long duration, the Thermal Energy Generation & Management Testbed shown in this figure will be located at a separate location on the space station. It incorporates a two-axis gimbal system to provide solar pointing during its seven year duration. The focal point insert will be changed to accommodate Brayton, Stirling, and Rankine thermal cycles. Radiator technology experiments can also be accommodated by this testbed. The placement of this facility on the space station will need further study due to its large size and mass.



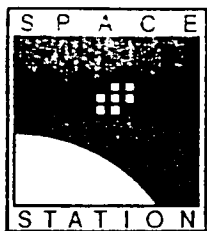
# Thermal Energy Generation & Management Testbed

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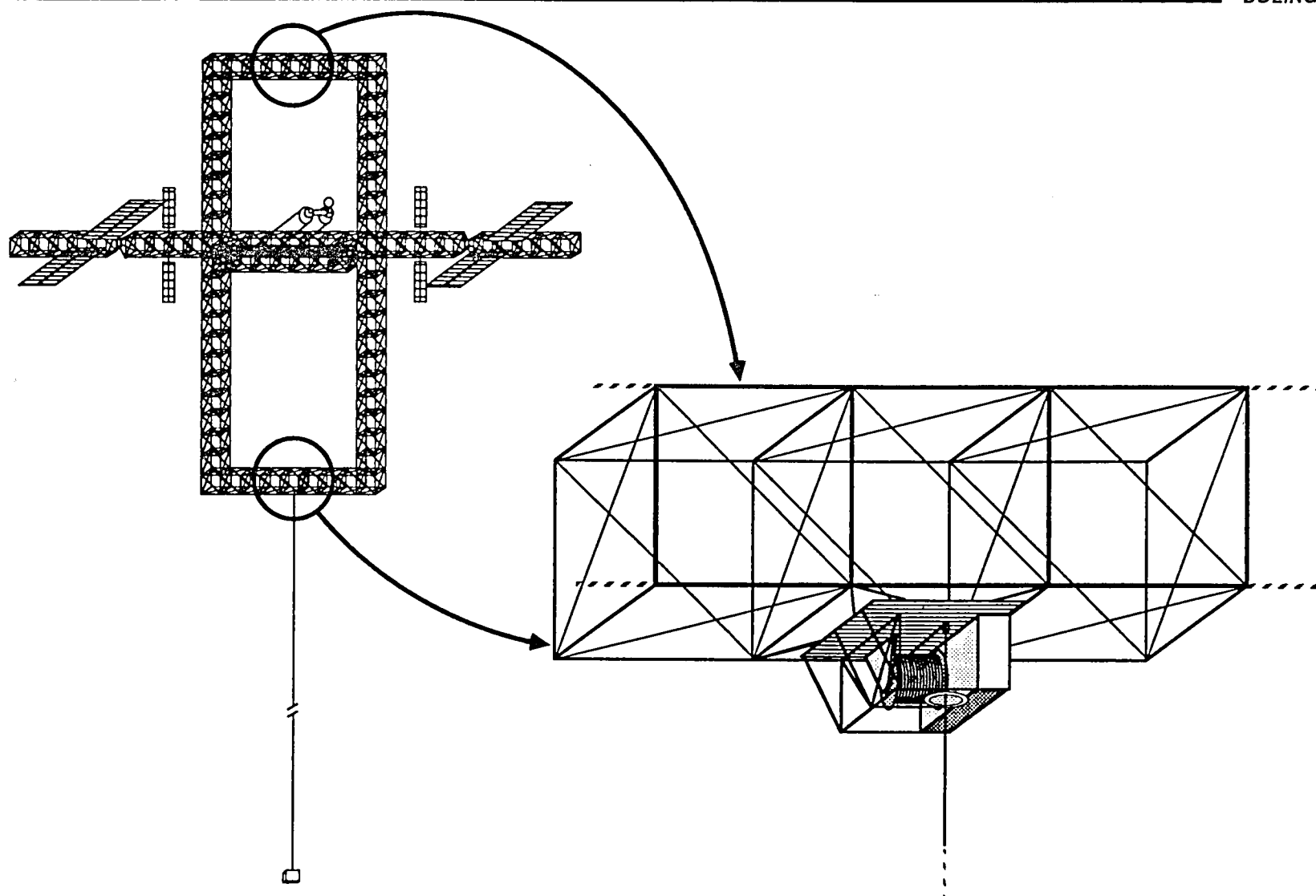
## Tether Testbed Facility

The Tether Testbed is also a unique facility and must be located at the center of either the upper or lower booms. Its operation relies on gravity gradients that produce forces that must be aligned with the center of mass of the space station. Details of this facility require further development and study.



# Tether Testbed Facility

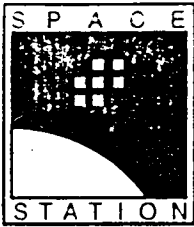
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## RT&E Laboratory Module

A dedicated, pressurized RT&E laboratory module is recommended for space station growth because all seven technology theme areas would benefit from it. The tasks in each theme area that could be accomplished in a RT&E Laboratory are shown in this figure. The RT&E Laboratory will permit human interaction with many experiments, will allow more efficient use of laboratory and data handling equipment, will support real-time evaluation of test specimens, and will provide a facility for maintenance and repair.



# Recommended Laboratory Module (Space Station growth)

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## RT&E Laboratory

- **Structural concepts**
  - Materials research
  - Advanced structural concepts evaluation & test
  - Structural sensors
  - Fabrication technology
  - On-orbit structural repairs
- **Fluid management**
  - Fluid sensors & measurement
  - Fluid behavior
- **Space environmental effects**
  - Materials evaluation
  - Electronics testing
  - Environmental research
- **Energy Systems & Thermal Mgmt.**
  - Component & sample evaluation
- **Information systems**
  - Sensor systems development & maintenance
  - Algorithm development and confirmation
  - Computer/data systems
- **Automation & robotics**
  - Robotics research & maintenance
- **In-space operations**
  - System test control station

## ACKNOWLEDGMENTS

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16. Abstract  A study was conducted to identify on-orbit integrated facility needs to support in-space technology experiments on the Space Station and associated free flyers. In particular, the first task was to examine the proposed technology development missions (TDMX's) from the model mission set and other proposed experimental facilities, both individually and by theme, to determine how and if the experiments might be combined, what equipment might be shared, what equipment might be used as generic equipment for continued experimentation, and what experiments will conflict with the conduct of other experiments or Space Station operations. Then using these results, determine on-orbit facility needs to optimize the implementation of technology payloads. Finally, develop one or more scenarios, design concepts, and outfitting requirements for implementation of onboard technology experiments.					
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